US010174648B2

(12) **United States Patent**
**Schmitt et al.**

(10) **Patent No.: US 10,174,648 B2**
(45) **Date of Patent: Jan. 8, 2019**

(54) **SYSTEMS AND METHODS FOR CAM PHASING CONTROL**

(71) Applicant: **HUSCO AUTOMOTIVE HOLDINGS LLC**, Waukesha, WI (US)

(72) Inventors: **Austin Schmitt**, Hartland, WI (US); **Allen Tewes**, Spirit Lake, IA (US); **Brian Heidemann**, Lake Mills, WI (US); **Michael Kujak**, Delafield, WI (US)

(73) Assignee: **HUSCO Automotive Holdings LLC**, Waukesha, WI (US)

( * ) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **15/682,998**

(22) Filed: **Aug. 22, 2017**

(65) **Prior Publication Data**

US 2018/0058273 A1 Mar. 1, 2018

**Related U.S. Application Data**

(60) Provisional application No. 62/378,314, filed on Aug. 23, 2016.

(51) **Int. Cl.**
***F01L 1/34*** (2006.01)
***F01L 1/344*** (2006.01)

(52) **U.S. Cl.**
CPC ............ ***F01L 1/3442*** (2013.01); ***F01L 1/344*** (2013.01); *F01L 2001/3443* (2013.01); *F01L 2001/3444* (2013.01); *F01L 2001/34489* (2013.01); *F01L 2001/34496* (2013.01)

(58) **Field of Classification Search**
CPC . F01L 1/3442; F01L 1/344; F01L 2001/3444; F01L 2001/3443; F01L 2001/34489; F01L 2001/34496
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

| | | | | |
|---|---|---|---|---|
| 6,763,791 | B2 * | 7/2004 | Gardner .................... | F01L 1/34 123/90.15 |
| 6,997,150 | B2 | 2/2006 | Simpson | |
| 9,115,610 | B2 | 8/2015 | Tewes et al. | |
| 2015/0330268 | A1 | 11/2015 | Tewes et al. | |

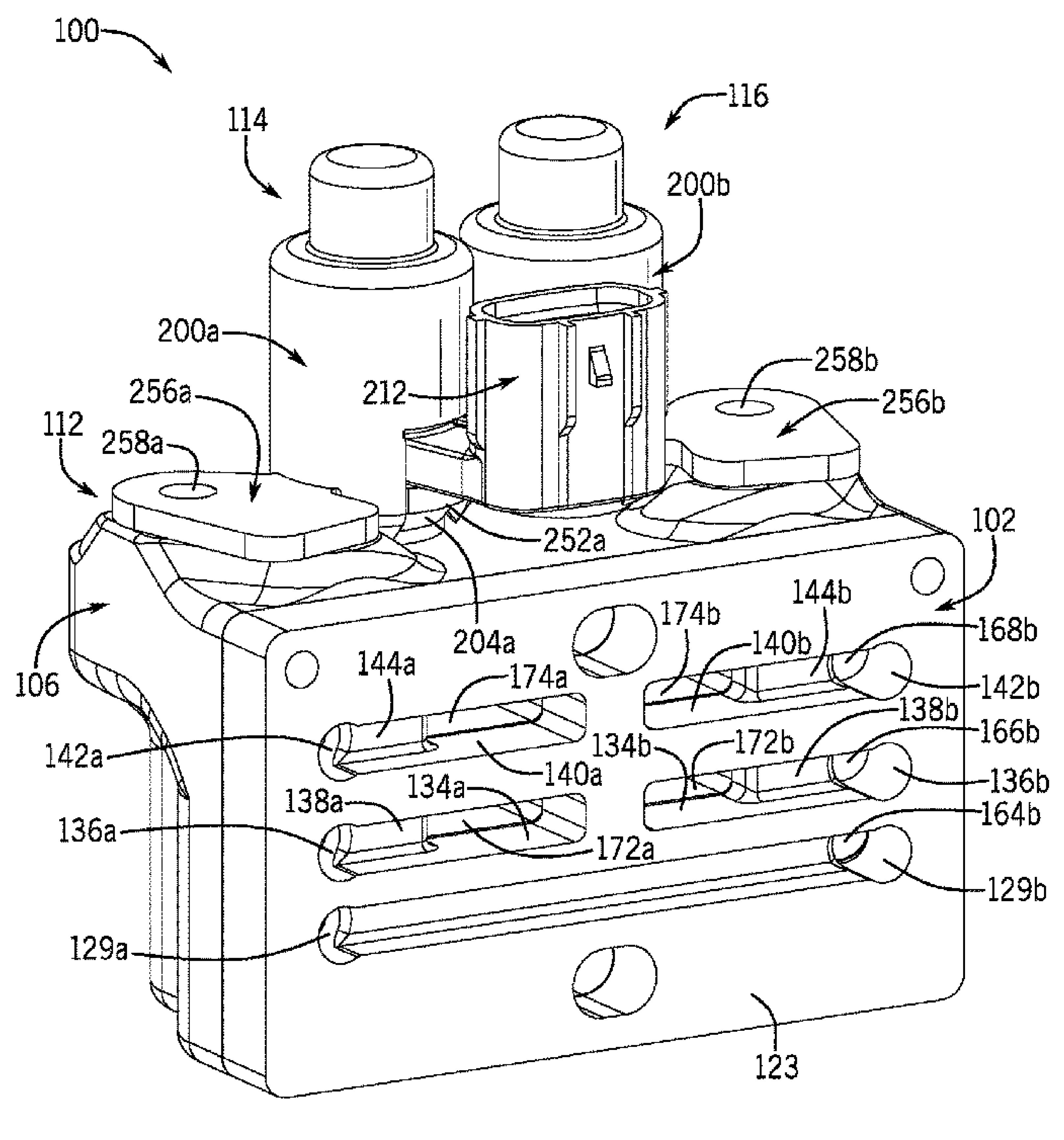
* cited by examiner

*Primary Examiner* — Zelalem Eshete
(74) *Attorney, Agent, or Firm* — Quarles & Brady LLP

(57) **ABSTRACT**

Systems and methods for a cam phasing control system are provided. In particular, systems and methods are provided for a cam phasing control system that can be configured to control a first cam phase actuator and a second cam phase actuator and selectively switch the operation thereof between a regenerative mode and an oil pressure actuation mode.

**26 Claims, 17 Drawing Sheets**



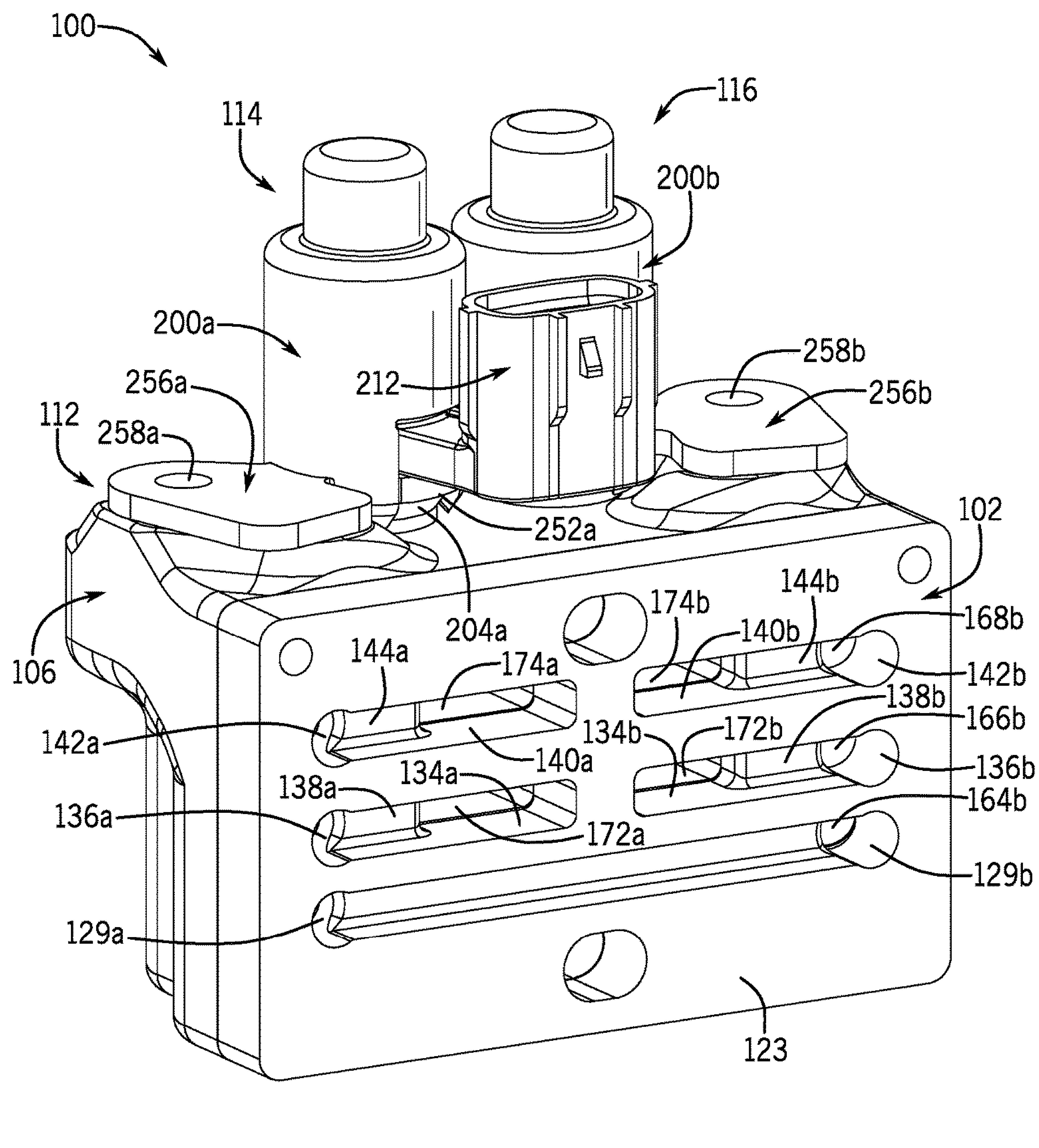

100
114
116
200b
200a
212
258b
256b
256a
112
258a
252a
102
204a
174b
144b
168b
106
144a
174a
140b
142b
142a
140a
134b
172b
138b
166b
138a
134a
136b
136a
172a
164b
129b
129a
123

FIG. 1

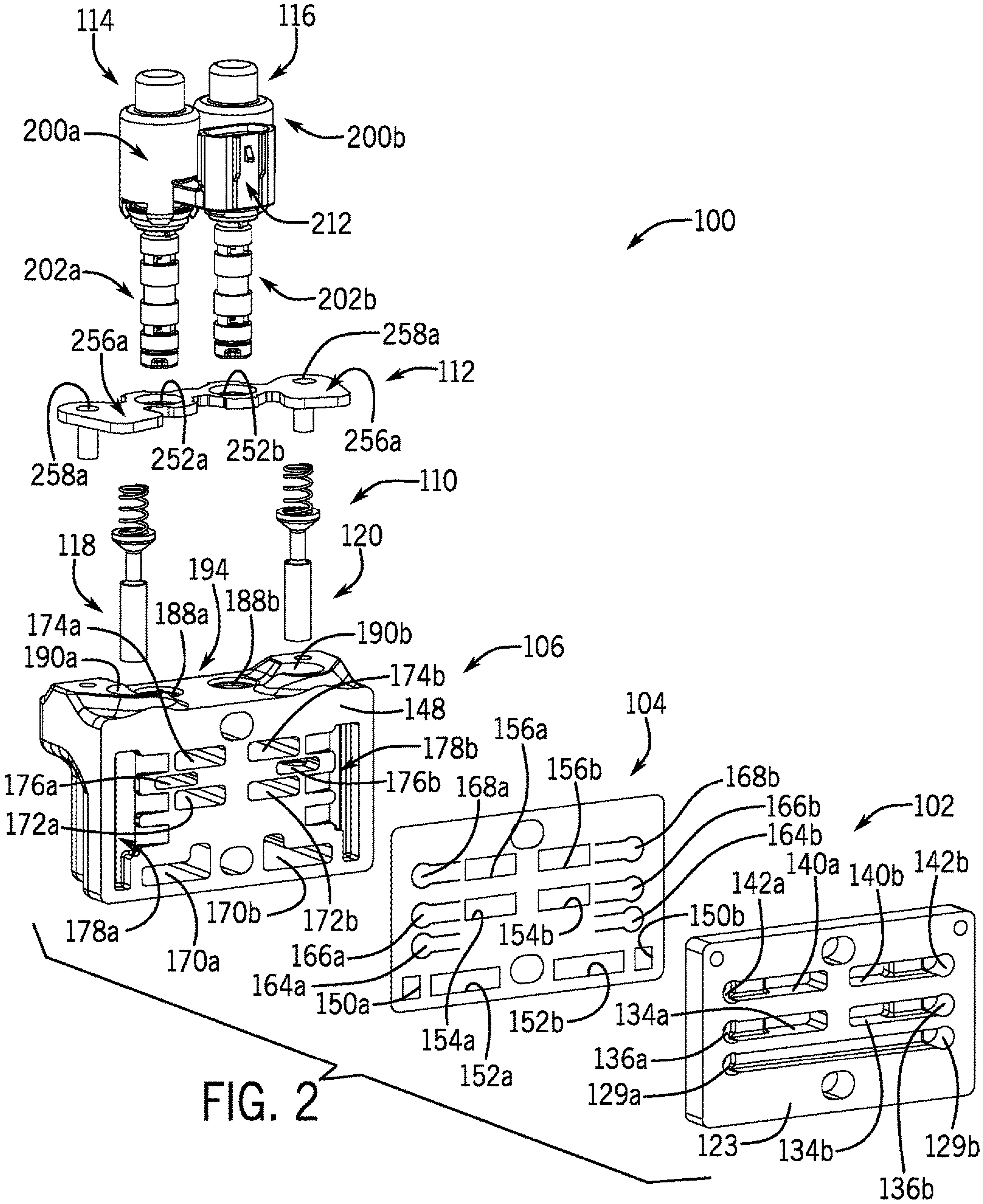

114
116
200a
200b
212
100
202a
202b
256a
258a
112
258a
252a
252b
256a
110
118
120
194
188a
188b
174a
190a
190b
106
174b
148
178b
176a
176b
172a
104
156a
156b
168a
168b
166b
164b
102
142a
140a
140b
142b
150b
154b
178a
170b
172b
170a
166a
164a
150a
154a
152a
152b
134a
136a
129a
123
134b
136b
129b

FIG. 2

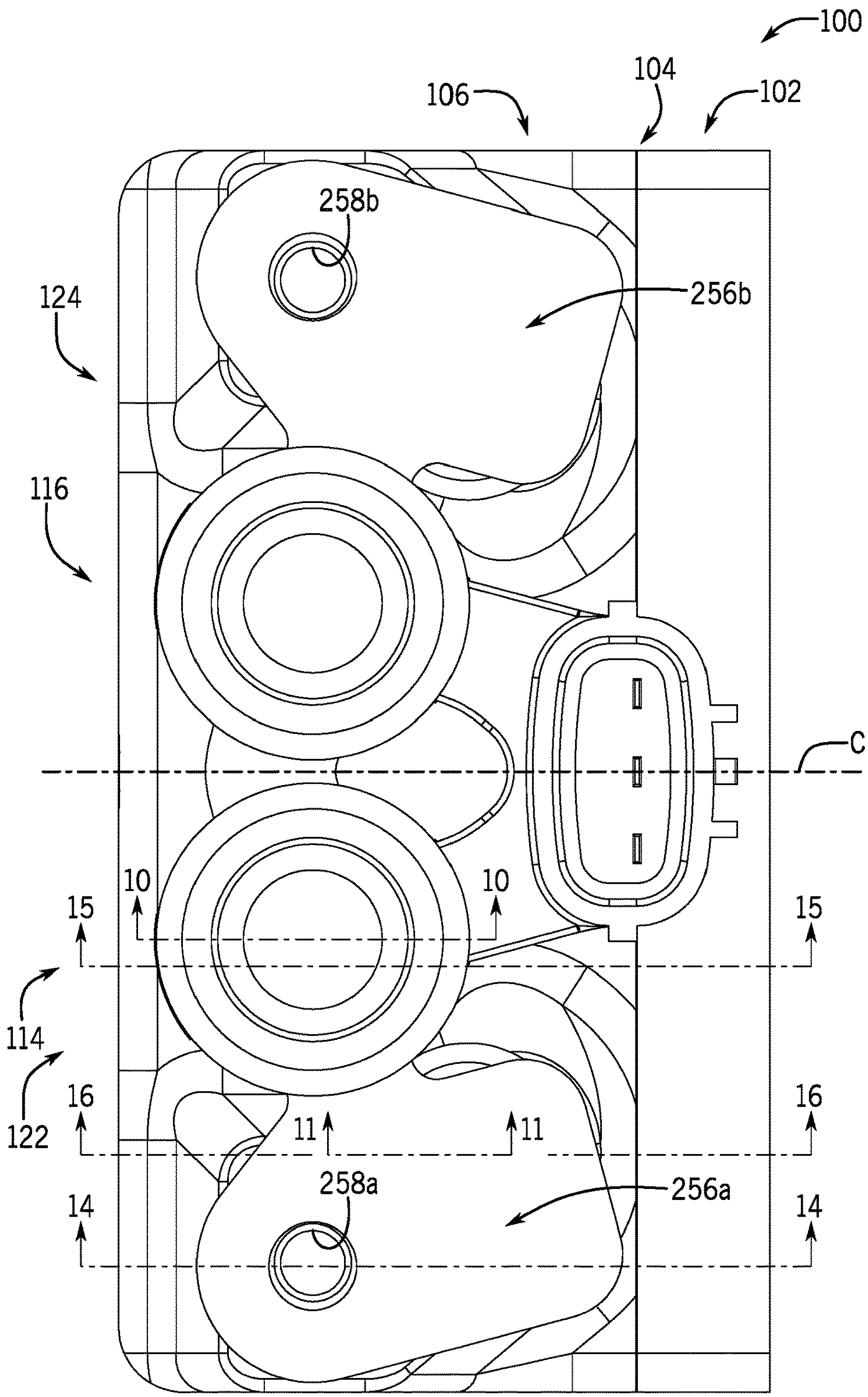

100
106
104
102
258b
256b
124
116
C
10
10
15
15
114
122
16
16
11
11
258a
256a
14
14

FIG. 3

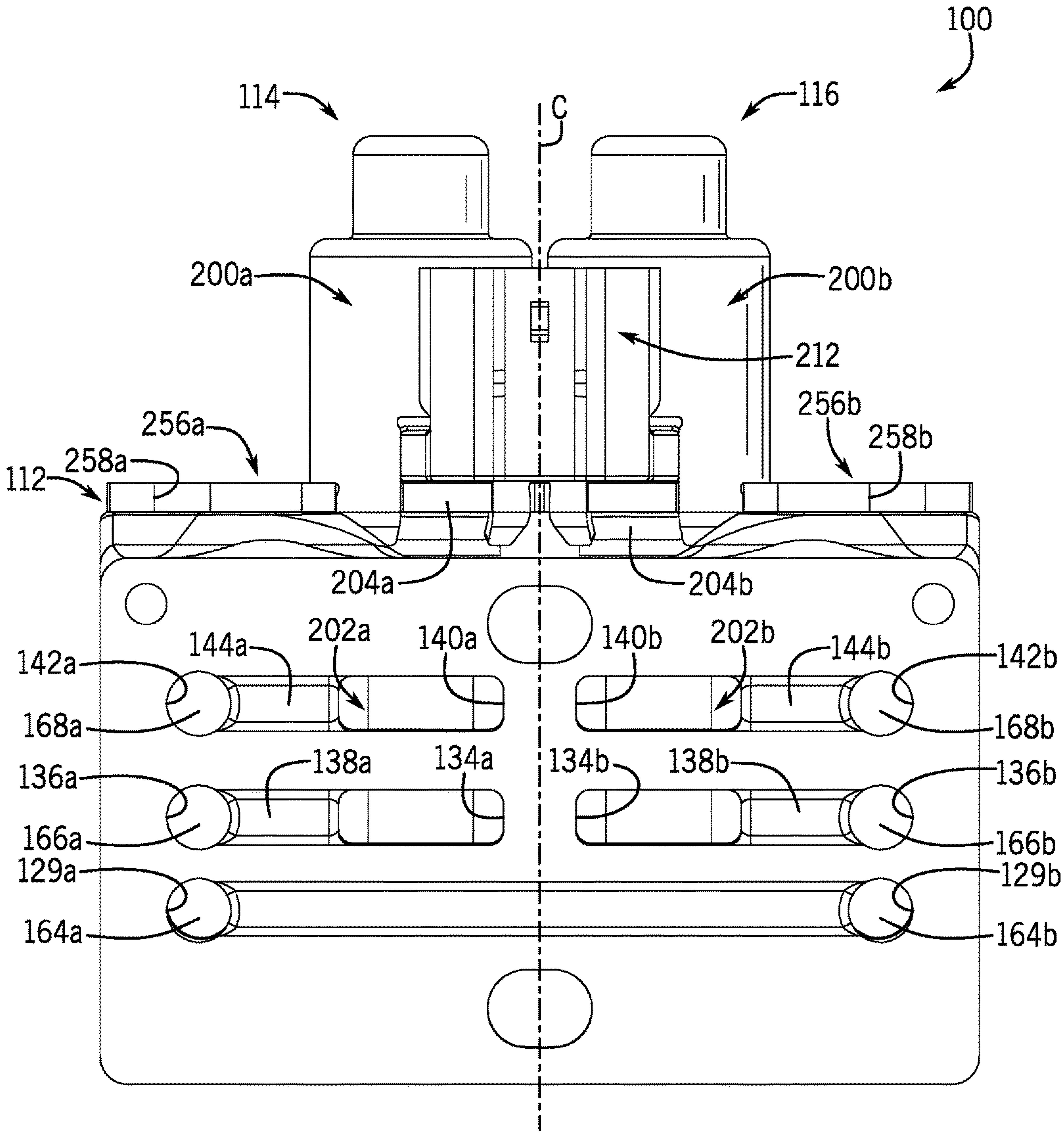

100
114
116
C
200a
200b
212
256a
256b
258a
258b
112
204a
204b
142a
144a
202a
140a
140b
202b
144b
142b
168a
168b
136a
138a
134a
134b
138b
136b
166a
166b
129a
129b
164a
164b

FIG. 4

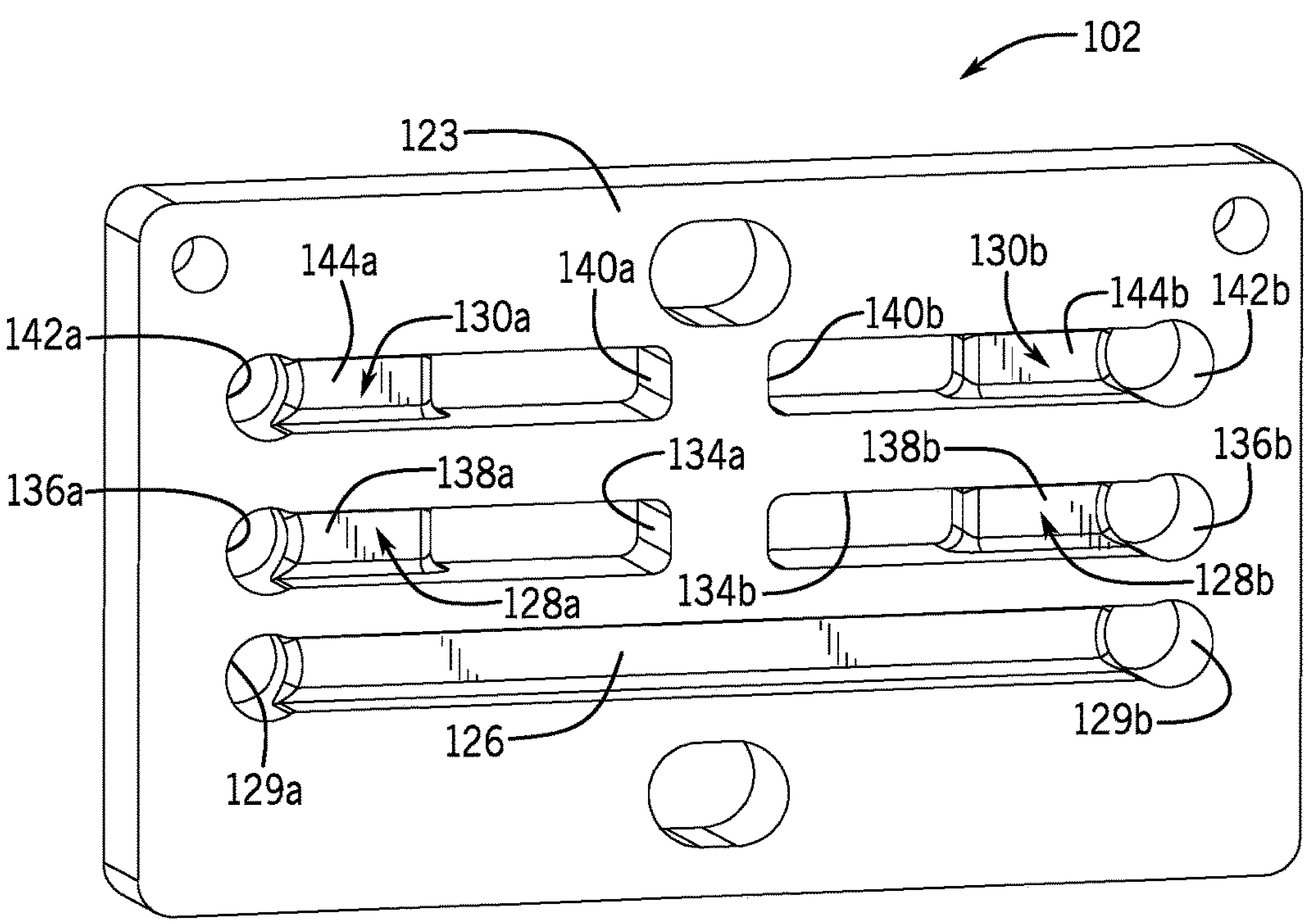
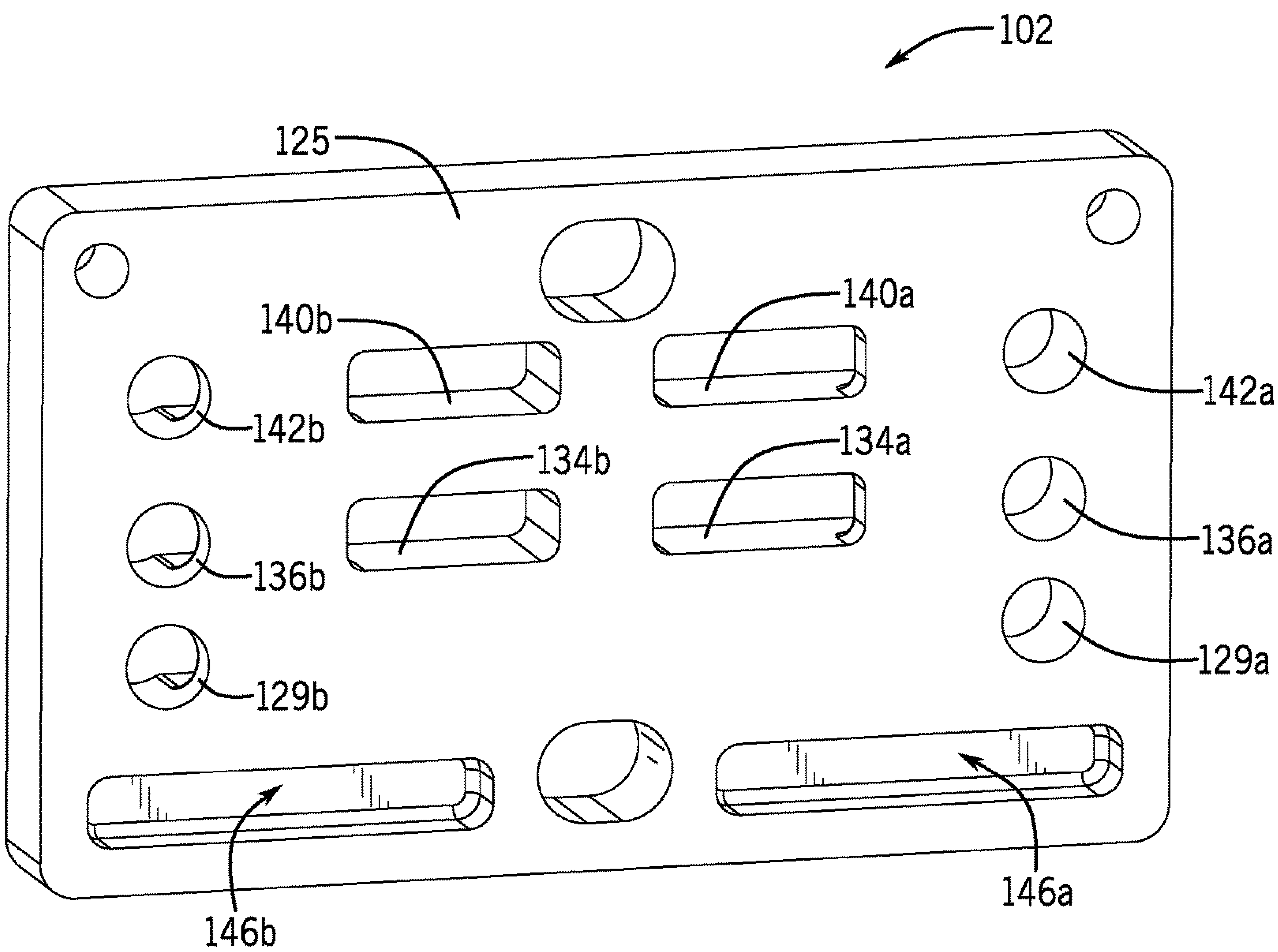
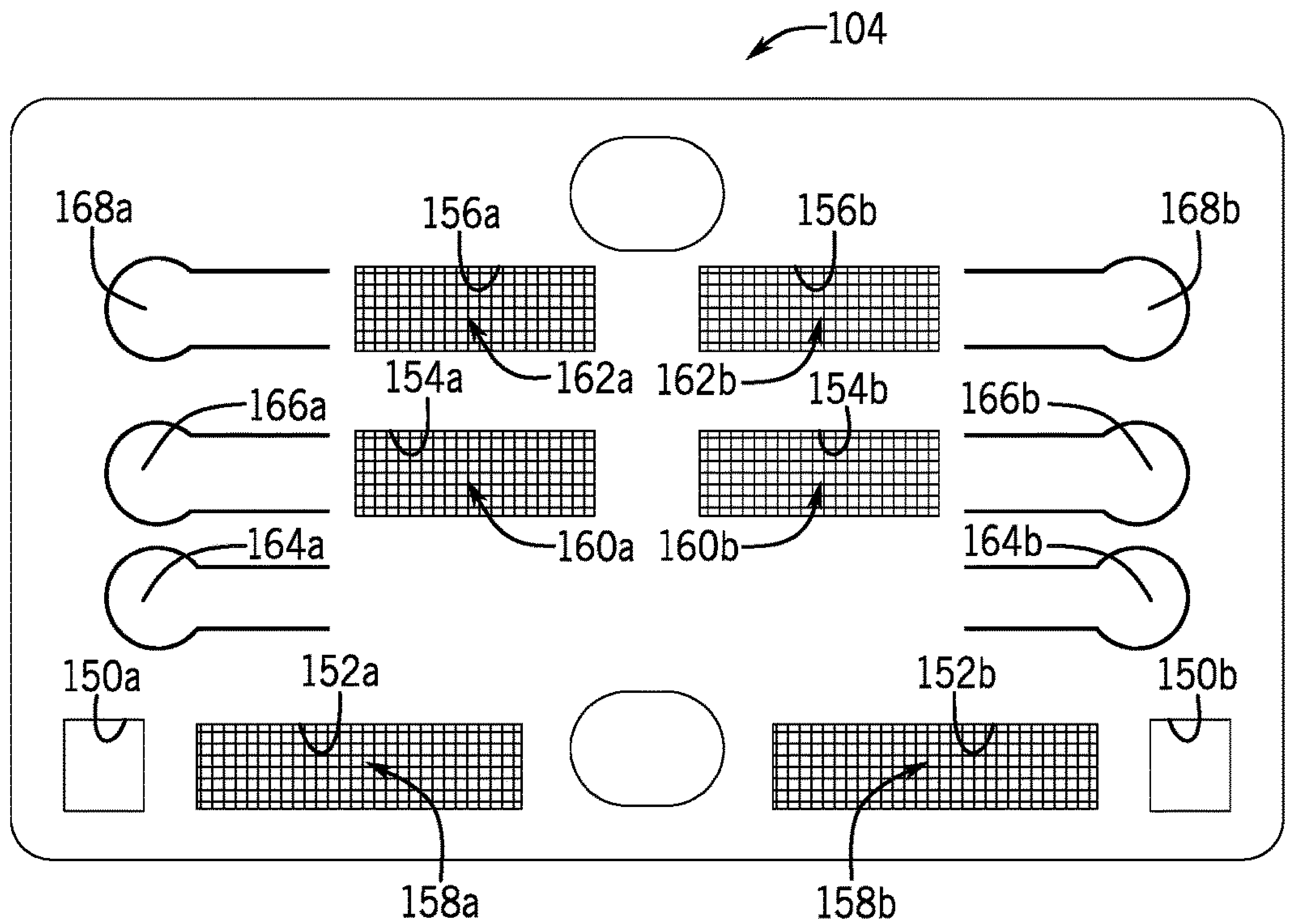

102
123
144a
140a
130b
144b
142b
142a
130a
140b
138b
136b
136a
138a
134a
128a
134b
128b
126
129b
129a

FIG. 5



102
125
140b
140a
142b
142a
134b
134a
136b
136a
129b
129a
146b
146a


FIG. 6



104
168a
156a
156b
168b
162a
162b
154a
154b
166a
166b
160a
160b
164a
164b
150a
152a
152b
150b
158a
158b


FIG. 7

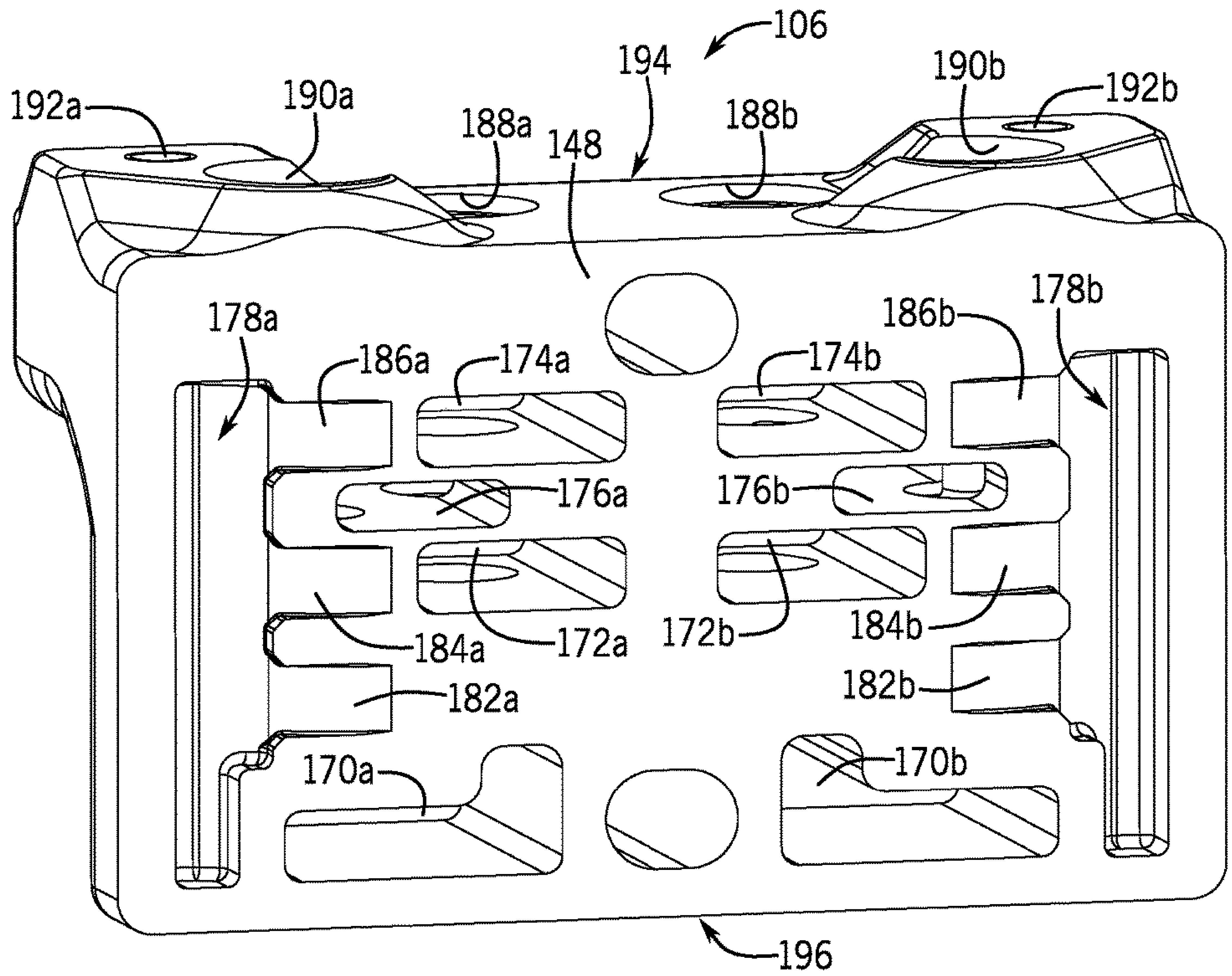

106
194
192a
190a
188a
148
188b
190b
192b
178a
186a
174a
174b
186b
178b
176a
176b
184a
172a
172b
184b
182b
182a
170a
170b
196

FIG. 8

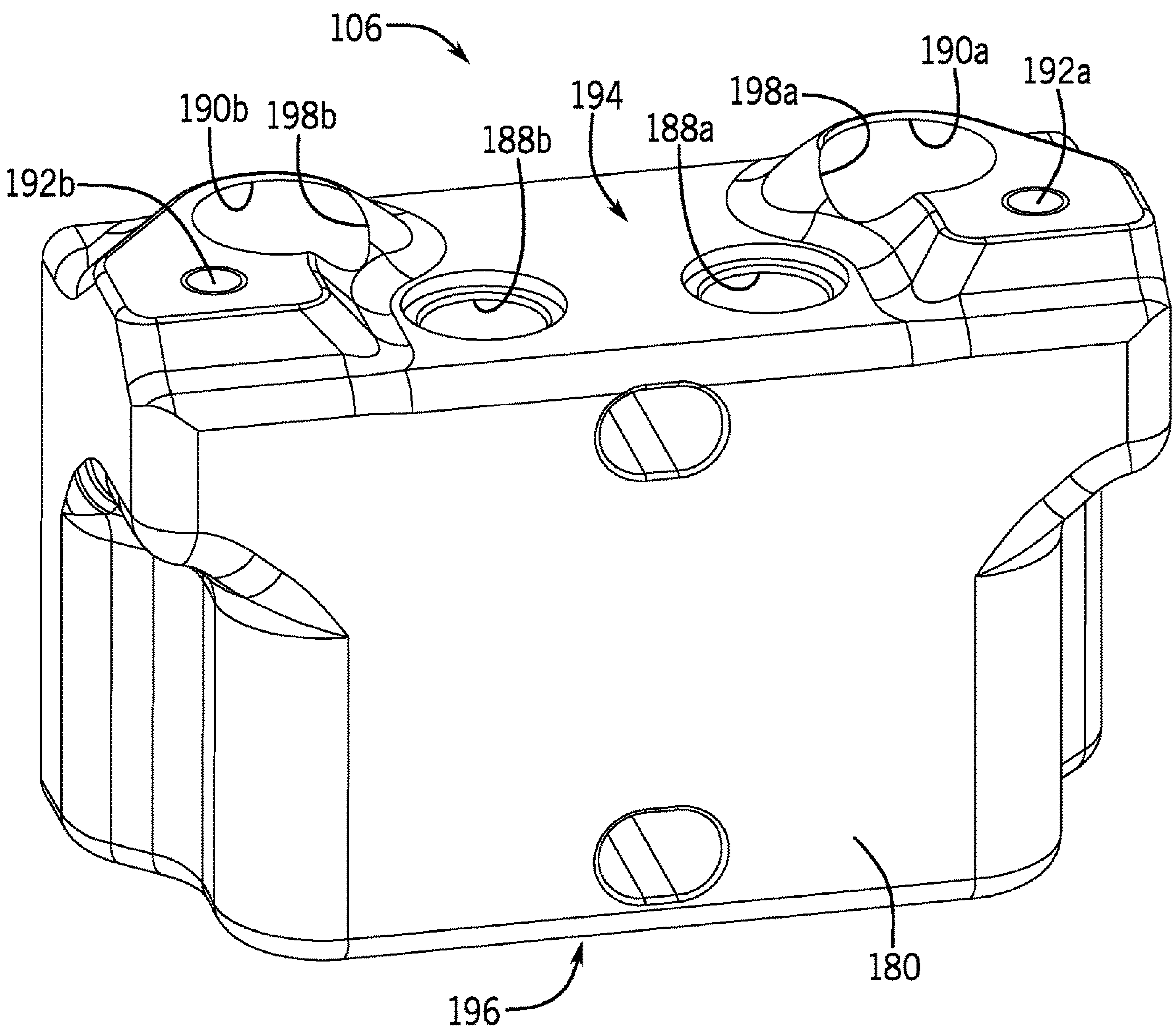



FIG. 9

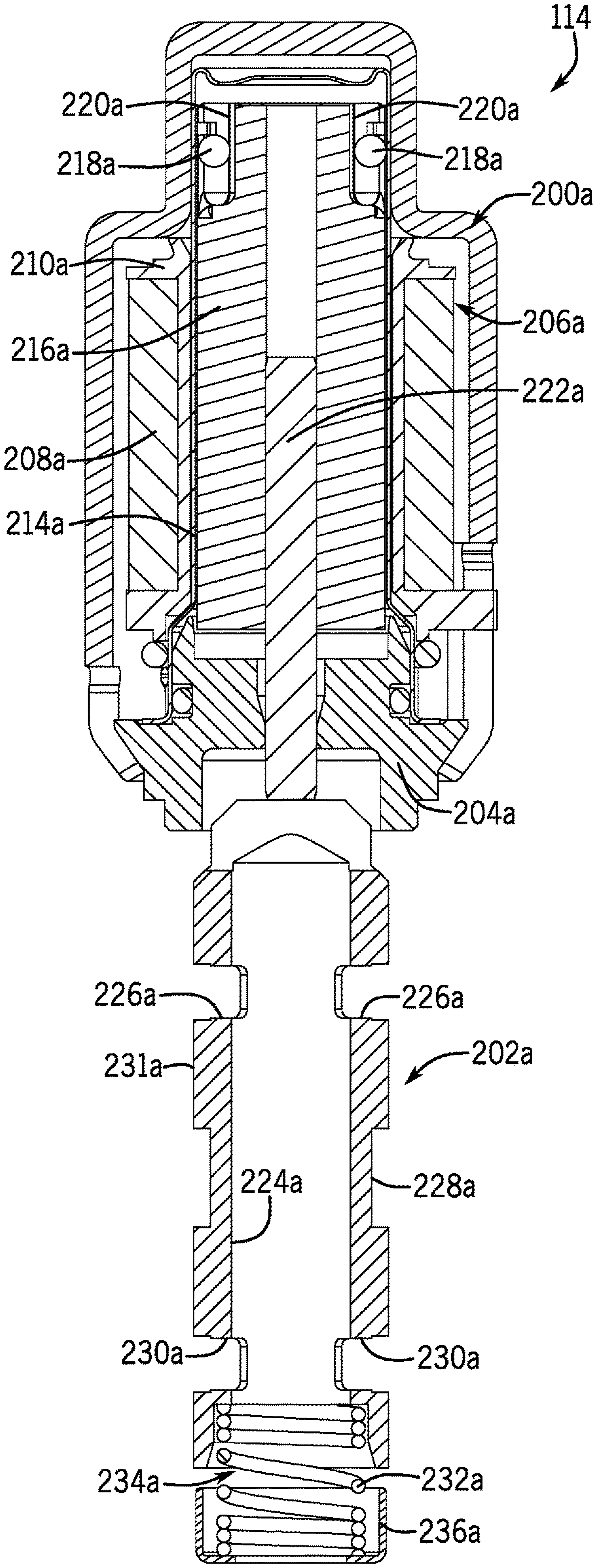

114
220a
220a
218a
218a
200a
210a
206a
216a
222a
208a
214a
204a
226a
226a
202a
231a
224a
228a
230a
230a
234a
232a
236a

FIG. 10

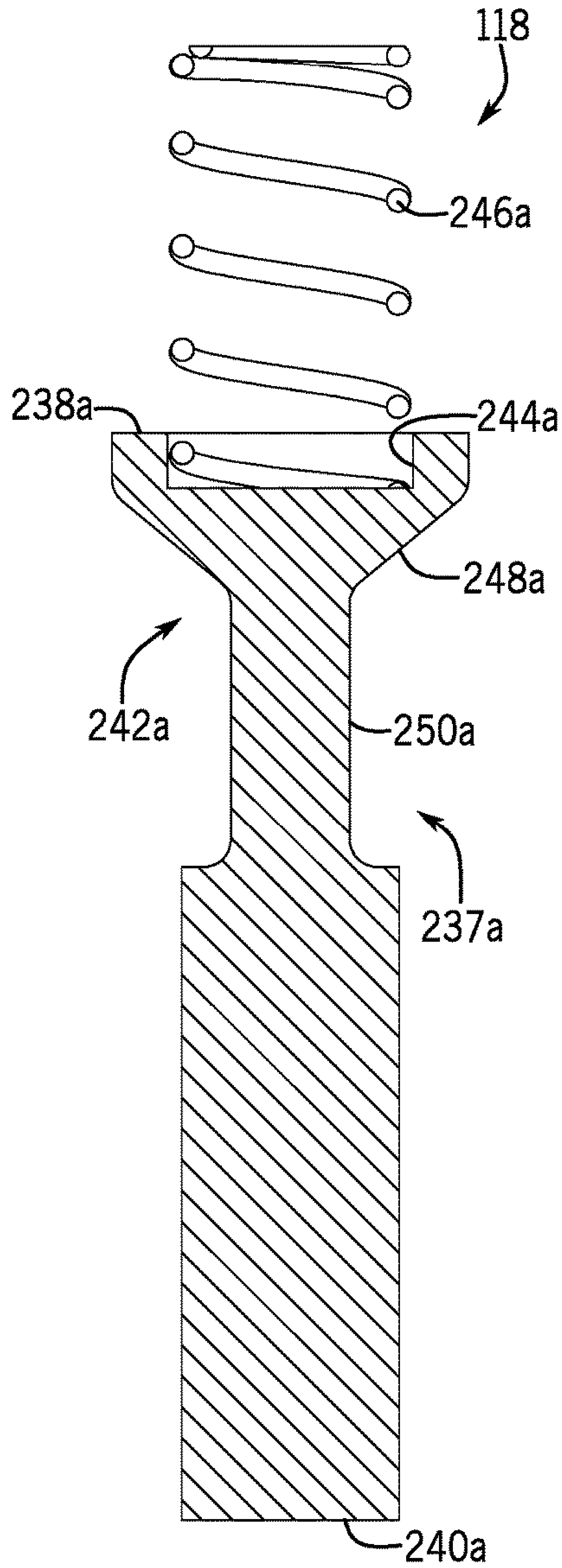

118
246a
238a
244a
248a
242a
250a
237a
240a

FIG. 11

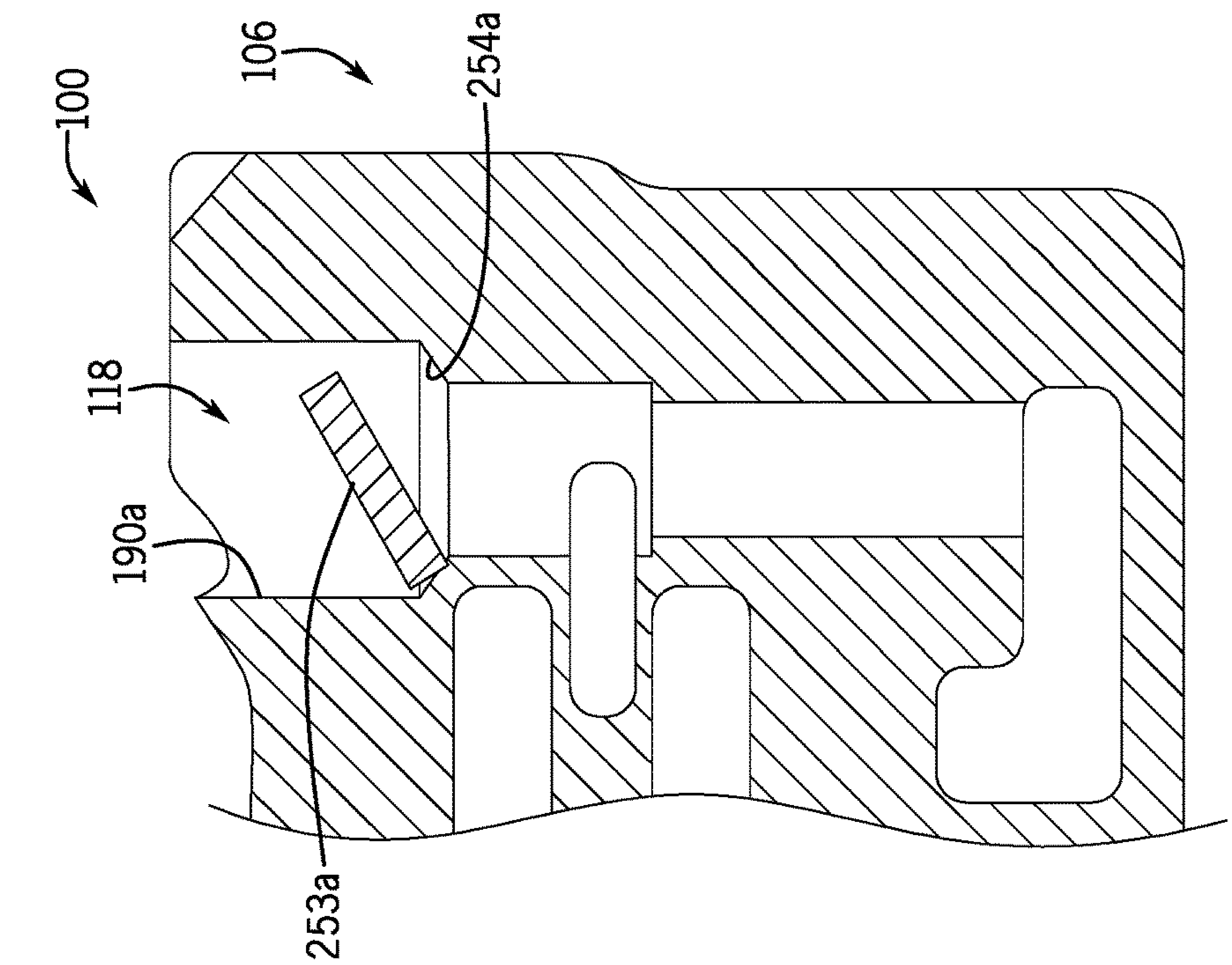



FIG. 13

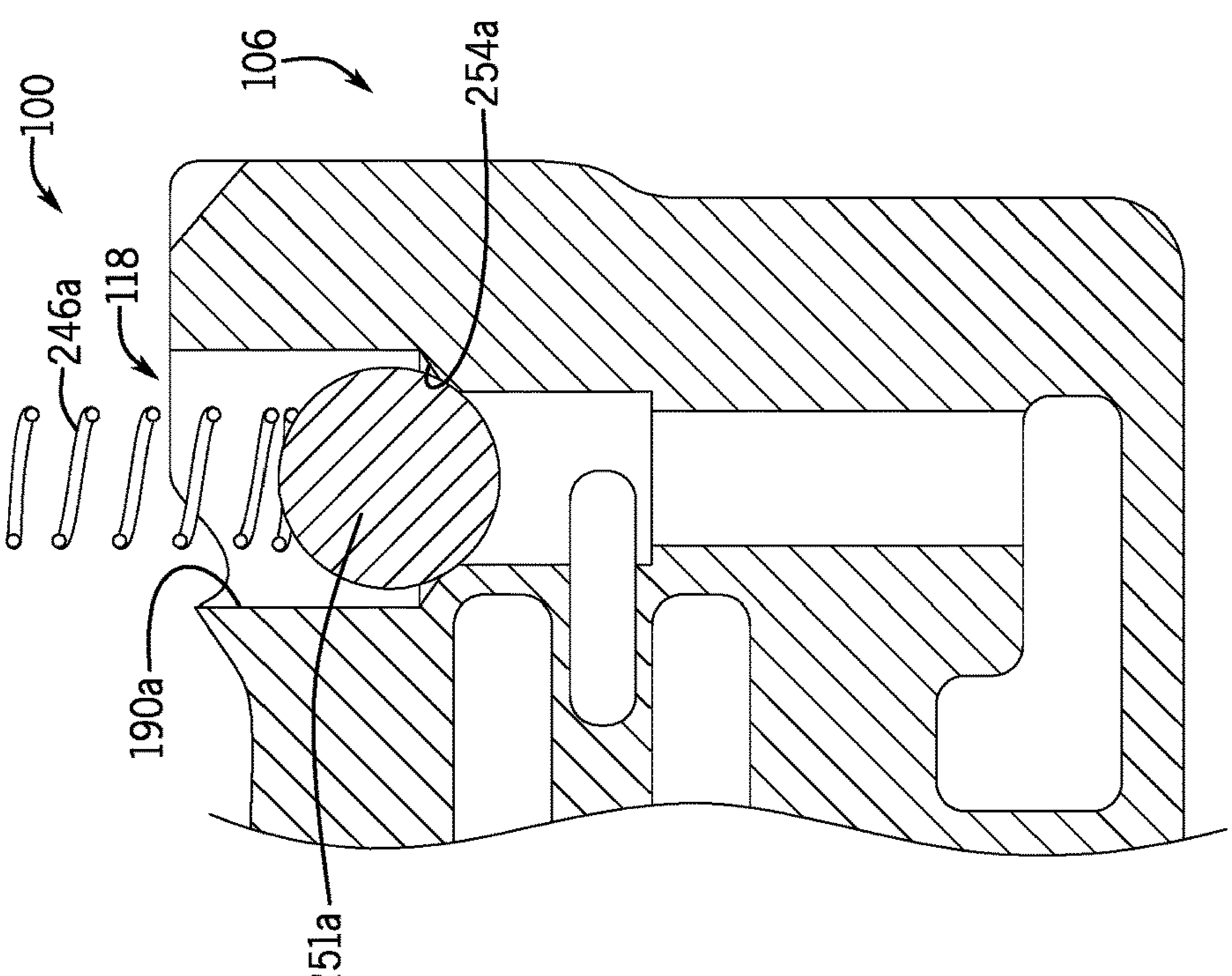



FIG. 12

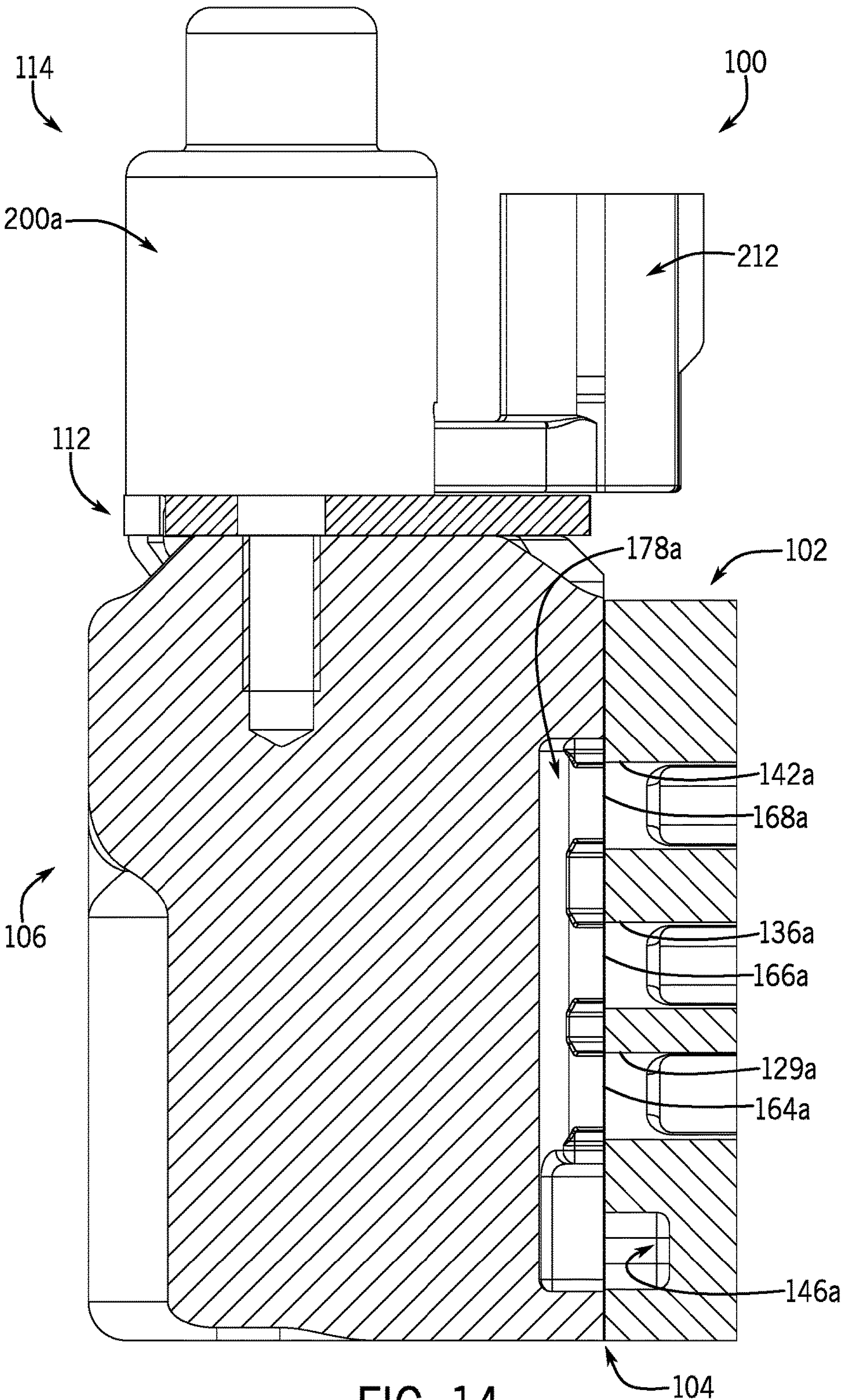

114
100
200a
212
112
178a
102
142a
168a
106
136a
166a
129a
164a
146a
104

FIG. 14

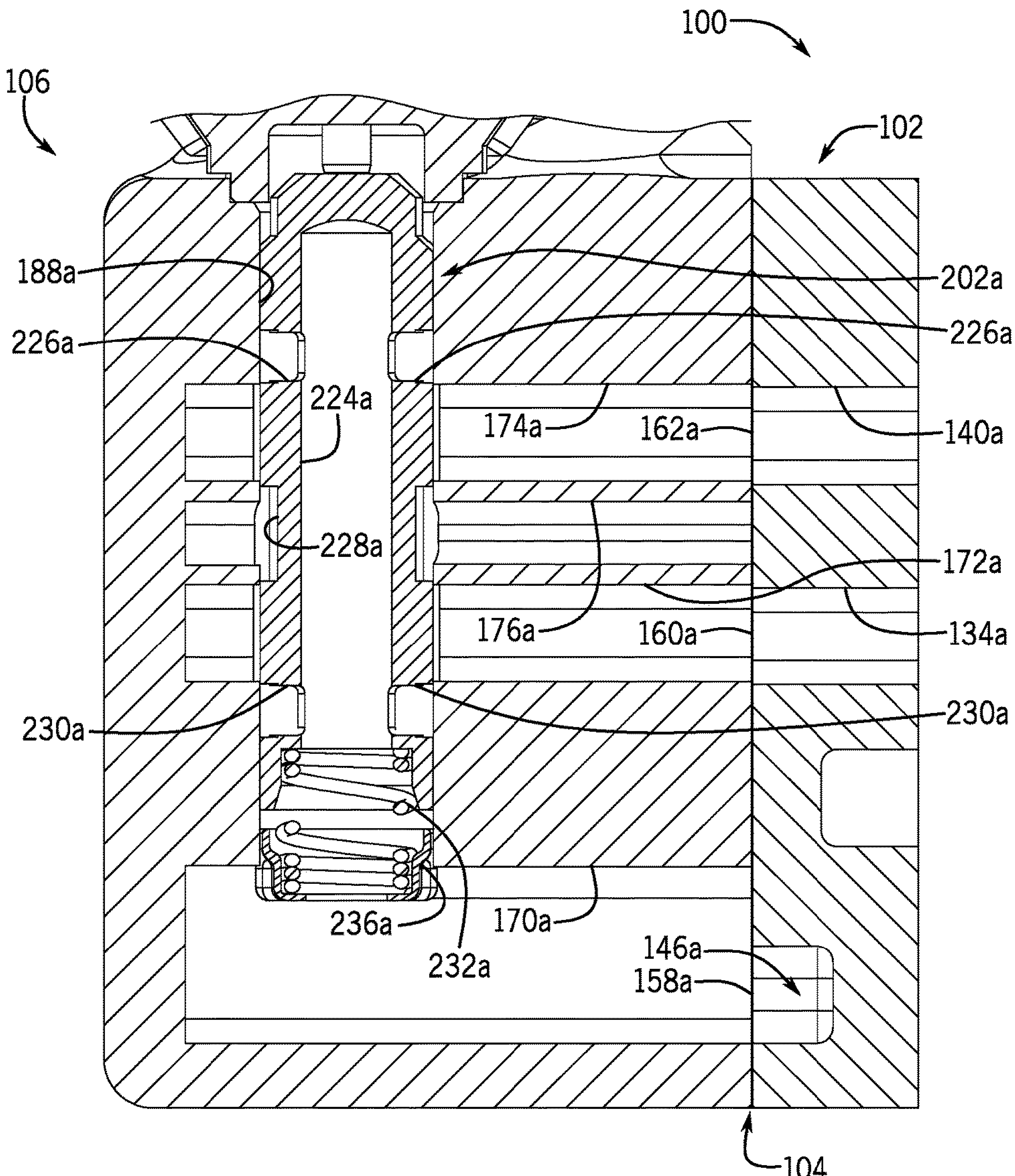

100
106
102
188a
202a
226a
226a
224a
174a
162a
140a
228a
172a
176a
160a
134a
230a
230a
236a
170a
232a
146a
158a
104

FIG. 15

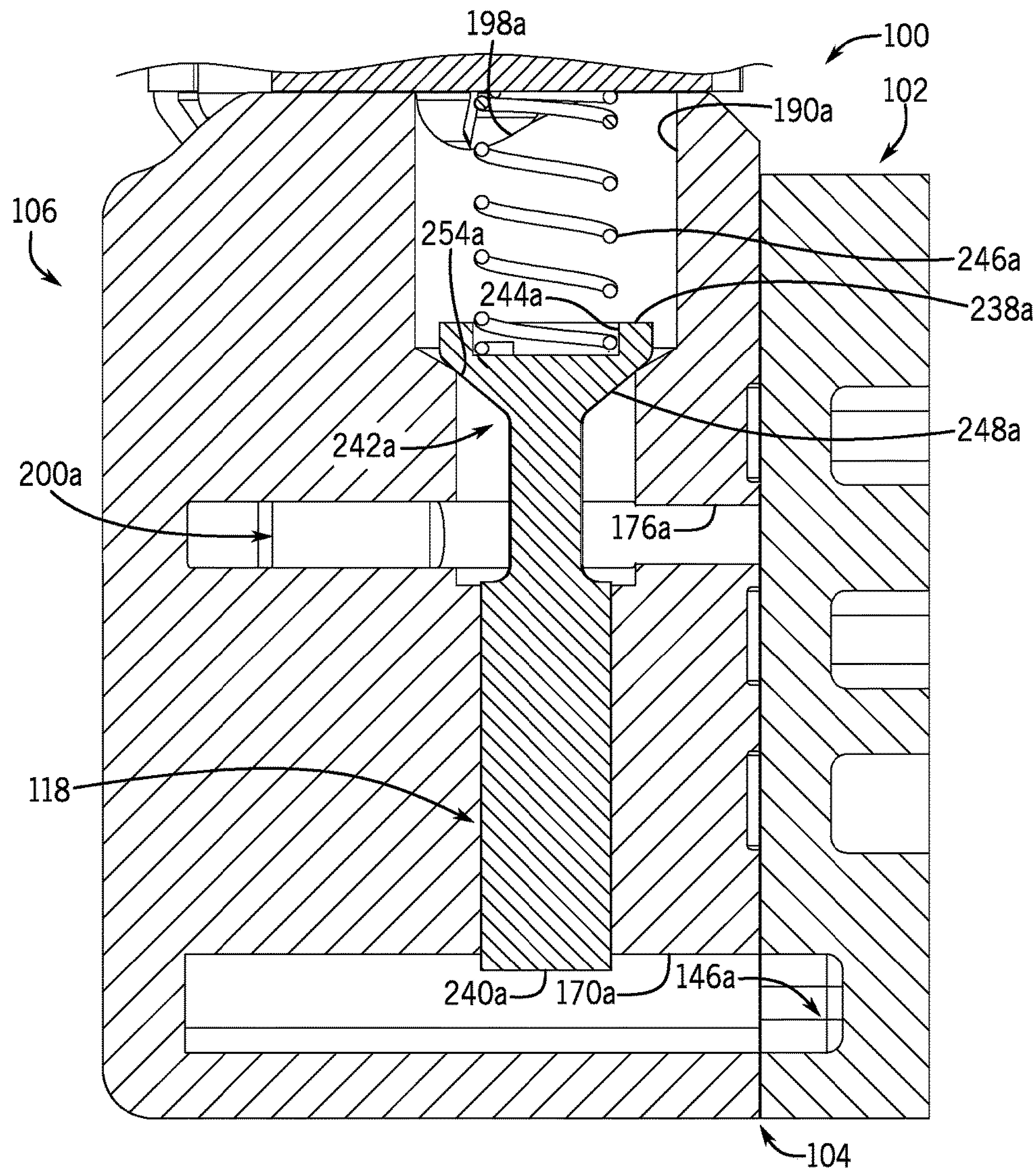

198a
100
190a
102
106
254a
246a
244a
238a
248a
242a
200a
176a
118
240a
170a
146a
104

FIG. 16

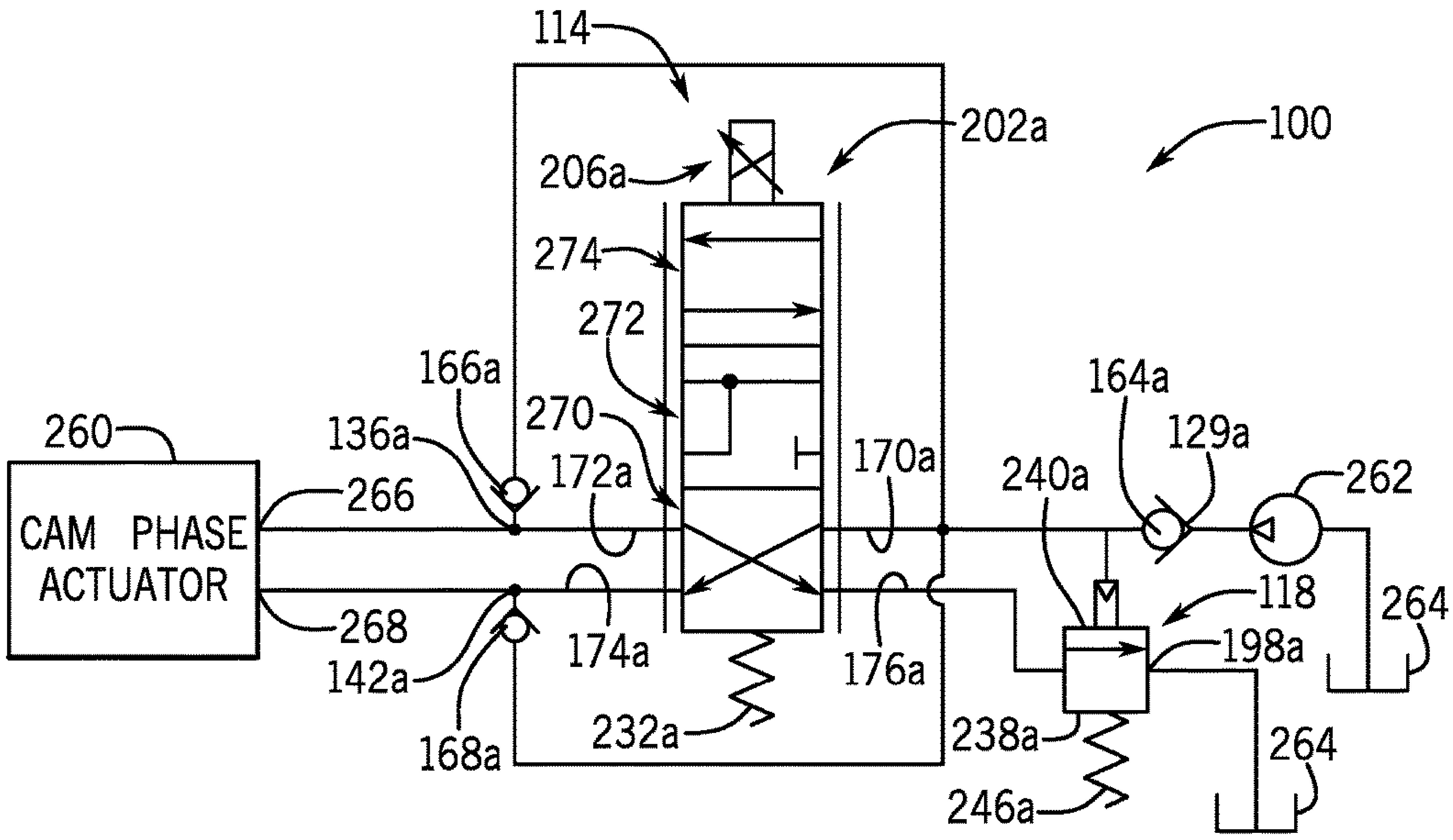

114
202a
100
206a
274
272
166a
270
164a
129a
260
136a
172a
170a
240a
262
266
CAM PHASE
ACTUATOR
118
264
268
198a
174a
176a
142a
232a
238a
264
168a
246a

FIG. 17

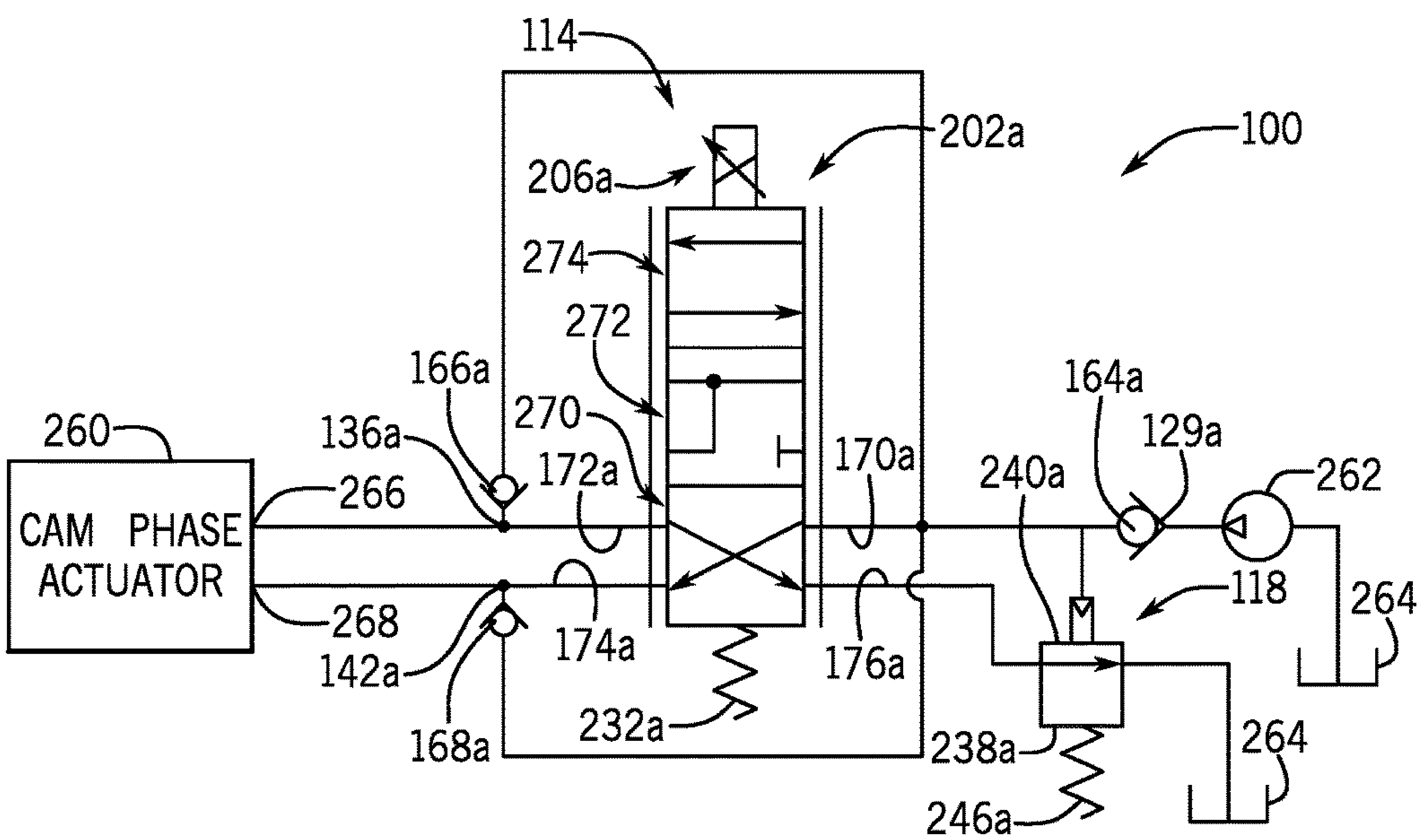

114
202a
100
206a
274
272
166a
270
164a
129a
260
136a
172a
170a
240a
262
266
CAM PHASE
ACTUATOR
118
264
268
174a
176a
142a
232a
238a
264
168a
246a

FIG. 18

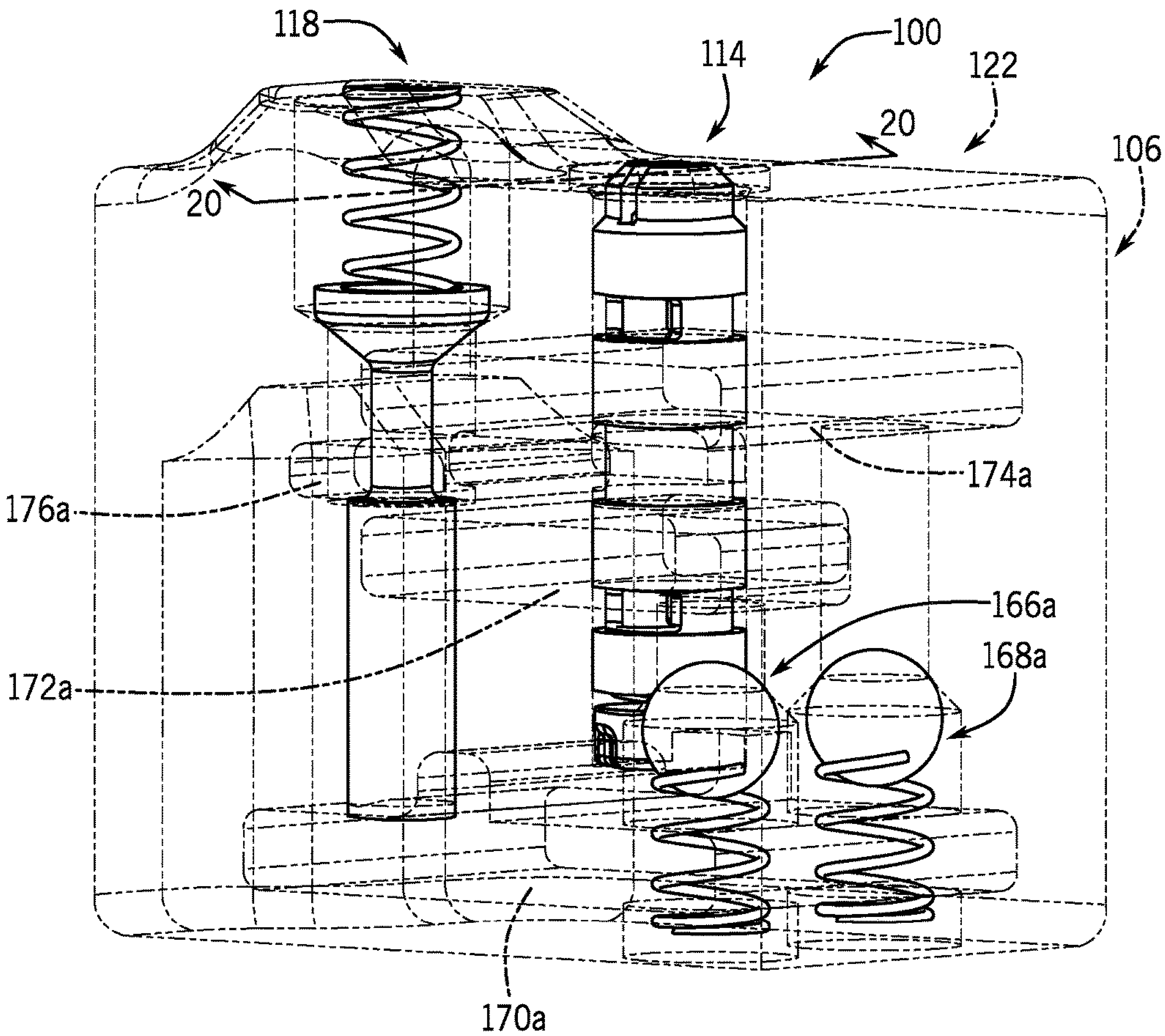



FIG. 19

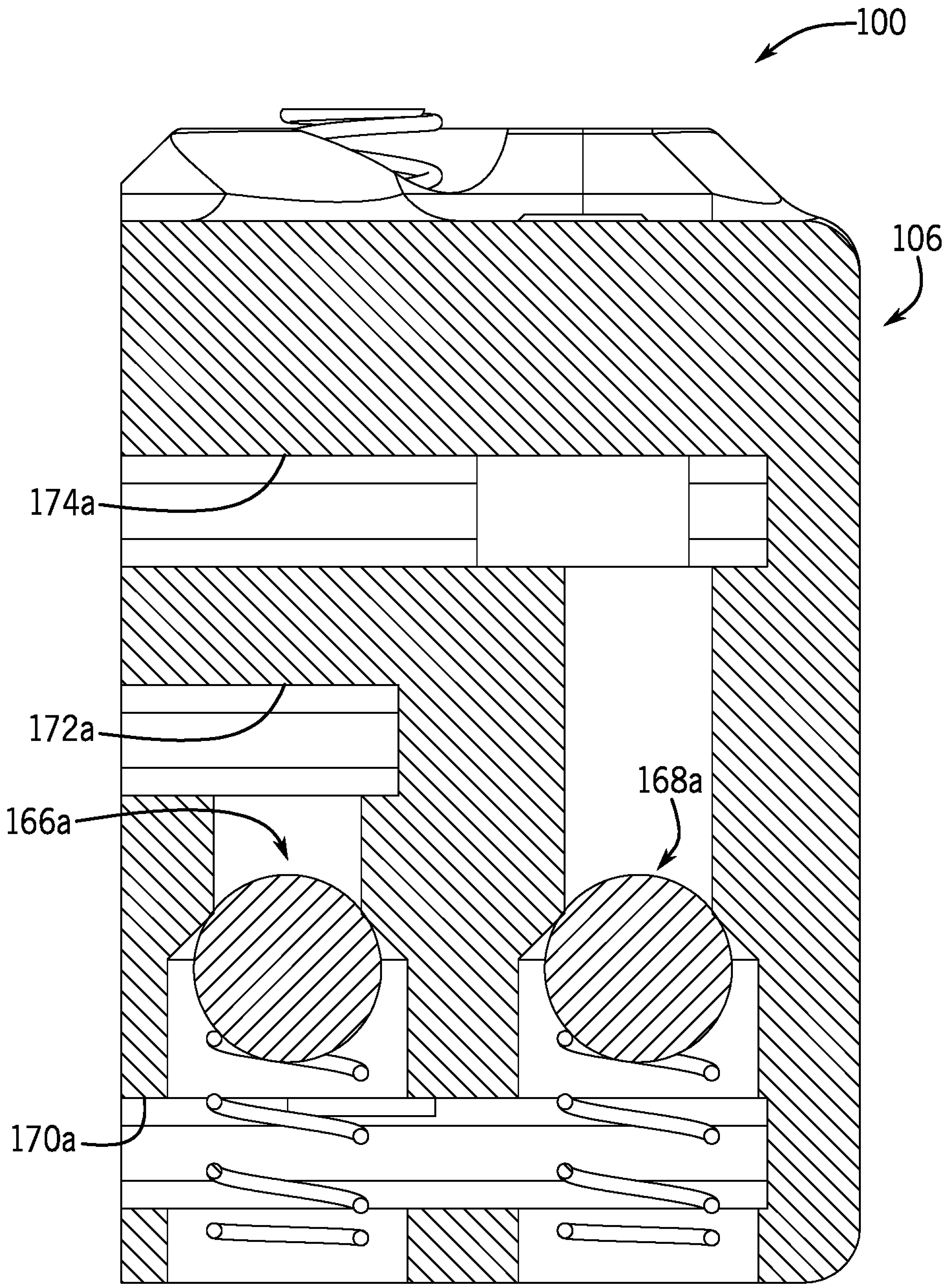



FIG. 20

# SYSTEMS AND METHODS FOR CAM PHASING CONTROL

## CROSS-REFERENCES TO RELATED APPLICATIONS

The present application is based on, claims priority to, and incorporates herein by reference in its entirety, U.S. Provisional Patent Application No. 62/378,314, filed on Aug. 23, 2016, and entitled "Systems and Methods for a Cam Phasing Control System."

## STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

Not Applicable.

## BACKGROUND

The present disclosure relates generally to variable valve timing for internal combustion engines and, more specifically, to systems and methods for cam phasing control.

Internal combustion engines include a plurality of cylinders with pistons received therein that are connected to drive a crank shaft. Each cylinder has two or more valves that control the flow of air into the cylinder and the flow of exhaust gases out of the cylinder. The intake and exhaust valves can be actuated at different times during the engine cycle (e.g., during the intake and exhaust strokes, respectively) by a cam shaft, which is mechanically connected to be rotated by the crank shaft.

It has been recognized that optimum engine performance (e.g., engine efficiency and emissions) can be obtained if the valve timing varies, for example, as a function of engine speed, engine load, atmospheric pressure, and other factors. During engine operation, a cam phase actuator (cam phaser) can be used to alter a rotational relationship of the cam shaft relative to the crank shaft (i.e., cam phasing), which, in turn, alters when the intake and/or exhaust valves open and close.

Currently, cam phasers can be hydraulically actuated, electronically actuated, or mechanically actuated. For hydraulically actuated cam phasers, there are two operational modes for cam phasing, namely, cam torque actuation mode and oil pressure actuation mode. Cam torque actuation mode utilizes torque pulses imposed on the cam shaft to rotate the cam phaser. Oil pressure actuated mode uses oil pressure from the engine's pump to rotate the cam phaser.

## BRIEF SUMMARY

The present disclosure provides systems and methods for cam phasing control. In particular, a cam phasing control system is disclosed that can be configured to control a first cam phase actuator and a second cam phase actuator, and selectively switch the operation thereof between a regenerative mode and an oil pressure actuation mode.

In one aspect, the present disclosure provides a cam phasing control system configured to be coupled to an internal combustion engine for controlling a flow of fluid to and from a cam phase actuator. The internal combustion engine includes a pump, a cam shaft, and a crank shaft. The cam phase actuator includes a first actuator port and a second actuator port. The cam phasing control system includes a manifold having a supply chamber, a first port chamber, a second port chamber, a regen chamber, and an outlet port. The cam phasing control system further includes at least one control valve having a solenoid and a spool moveable



between a plurality of positions in response to activation of the solenoid. The spool is slidably received within the manifold. The cam phasing control system further includes at least one regen valve arranged within the manifold and in fluid communication with the regen chamber. The at least one regen valve is moveable between a first regen valve position where fluid communication is inhibited from the regen chamber through the outlet port and a second regen valve position where fluid communication is provided from the regen chamber through the outlet port. The at least one regen valve is moveable between the first position and the second position in response to a pressure in the supply chamber. When the at least one regen valve is in the first regen valve position, the cam phase actuator is operable in a regenerative mode, and when the at least one regen valve is in the second poppet position, the cam phase actuator is operable in an oil pressure actuated mode.

In another aspect, the present disclosure provides a filter plate for a cam phasing control system. The cam phasing control system includes a supply port, one or more workports, and one or more regen ports. The filter plate includes one or more check valves. One of the one or more check valves is arranged to enable fluid to flow through the supply port only in a desired direction. The filter plate further includes one or more filters. One of the one or more filters is arranged to filter fluid flowing from the supply port.

The foregoing and other aspects and advantages of the invention will appear from the following description. In the description, reference is made to the accompanying drawings which form a part hereof, and in which there is shown by way of illustration a preferred embodiment of the invention. Such embodiment does not necessarily represent the full scope of the invention, however, and reference is made therefore to the claims and herein for interpreting the scope of the invention.

## BRIEF DESCRIPTION OF DRAWINGS

The invention will be better understood and features, aspects and advantages other than those set forth above will become apparent when consideration is given to the following detailed description thereof. Such detailed description makes reference to the following drawings.

FIG. **1** is a top, front, left isometric view of a cam phasing control system according to one aspect of the present disclosure.

FIG. **2** is an exploded top, front, left isometric view of the cam phasing control system of FIG. **1**.

FIG. **3** is a top view of the cam phasing control system of FIG. **1**.

FIG. **4** is a front view of the cam phasing control system of FIG. **1**.

FIG. **5** is a top, front, left isometric view of an end plate of the cam phasing control system of FIG. **1**.

FIG. **6** is a top, back, right isometric view of an end plate of the cam phasing control system of FIG. **1**.

FIG. **7** is a front view of a filter plate of the cam phasing control system of FIG. **1**.

FIG. **8** is a top, front, left isometric view of a manifold of the cam phasing control system of FIG. **1**.

FIG. **9** is a top, back, right isometric view of a manifold of the cam phasing control system of FIG. **1**.

FIG. **10** is a cross-sectional view of a first control valve of the cam phasing control system of FIG. **1** taken along line **10-10** of FIG. **3**.

FIG. **11** is a cross-sectional view of a first regen valve in the form of a first poppet and a biasing element of the cam phasing control system of FIG. **1** taken along line **11-11** of FIG. **3**.

FIG. **12** is a schematic illustration of a first regen valve in the form of a ball and a biasing element of the cam phasing control system of FIG. **1** according to one aspect of the present disclosure.

FIG. **13** is a schematic illustration of a first regen valve in the form of a swing of the cam phasing system of FIG. **1** according to another aspect of the present disclosure

FIG. **14** is a cross-sectional view of the cam phasing control system of FIG. **1** taken along line **14-14** of FIG. **3**.

FIG. **15** is a cross-sectional view of the cam phasing control system of FIG. **1** taken along line **15-15** of FIG. **3**.

FIG. **16** is a cross-sectional view of the cam phasing control system of FIG. **1** taken along line **16-16** of FIG. **3**.

FIG. **17** is a hydraulic schematic illustrating operation of the cam phasing control system of FIG. **1** in a regen mode.

FIG. **18** is a hydraulic schematic illustrating operation of the cam phasing control system of FIG. **1** in an oil pressure actuated mode.

FIG. **19** is a top, front, left isometric view of a first side of a cam phasing control system with a manifold of the cam phasing control system transparent according to another aspect of the present disclosure.

FIG. **20** is a cross-sectional view of the cam phasing control system of FIG. **19** taken along line **20-20**.

## DETAILED DESCRIPTION

FIGS. **1-4** illustrate a cam phasing control system **100** according to one non-limiting example of the present disclosure. As shown in FIGS. **1-4**, the cam phasing control system **100** can include an end plate **102**, a filter plate **104**, a manifold **106**, one or more control valves **108**, one or more poppets **110** and a mounting bracket plate **112**. In the illustrated cam phasing control system **100**, the one or more control valves **108** can include a first control valve **114** and a second control valve **116**, and the one or more poppets **110** can include a first regen valve **118** and a second regen valve **120**. The cam phasing control system **100** can be symmetrical about a center plane C (FIGS. **3** and **4**). Each of the end plate **102**, the filter plate **104**, the manifold **106**, and the mounting bracket plate **112** can be symmetrical about the center plane C. The center plane C can divide the cam phasing control system **100** into a first side **122** and a second side **124**. The first side **122** can include the first control valve **114** and the first regen valve **118**, and can be configured to control a first cam phase actuator (not shown). The second side **124** can include the second control valve **116** and the second regen valve **120**, and can be configured to control a second cam phase actuator (not shown). Thus, the cam phasing control system **100** provides a single package that enables the control of cam phasing for two cam shafts on an internal combustion engine.

The components and design of the first side **122** of the cam phasing control system **100** can be similar to the components and design of the second side **124** of the cam phasing control system **100**. As such, the following description of the components, design, and operation of the first side **122** of the cam phasing control system **100** also applies to the components, design, and operation of the second side **124** of the cam phasing control system **100**. Similar features are identified using like reference numerals with the features on the first side **122** denoted using the suffix "a" and the features on the second side **124** denoted using the suffix "b." That is, for each feature described using a reference numeral with the suffix "a," the cam phasing control system **100** includes a corresponding symmetric feature arranged on the second side **124** labeled using the suffix "b." It should also be appreciated that the first control valve **114** and the second control valve **116** can be similar in design and functionality and, thus, the following description of the first control valve **114** also applies to the second control valve **116**. Additionally, the first regen valve **118** and the second regen valve **120** can be similar in design and functionality and, thus, the following description of the first regen valve **118** also applies to the second regen valve **120**.

Turning to FIGS. **5** and **6**, the end plate **102** can include a front surface **123** and a back surface **125**. The front surface **123** of the end plate **102** can include a supply recess wall **126**, a first port recess **128*a***, and a second port recess **130*a***. The supply recess wall **126** can extend partially into the end plate **102** (i.e., recessed into the front surface **123** to a location between the front surface **123** and the back surface **125**) and a supply port **129*a*** can be arranged at a distal end thereof. The supply port **129*a*** can extend completely through the end plate **102** to enable fluid flow therethrough. The first port recess **128*a*** can include a first workport **134*a***, a first regen port **136*a***, and a first recess wall **138*a*** arranged between the first workport **134*a*** and the first regen port **136*a***. The first workport **134*a*** and the first regen port **136*a*** can be arranged at opposing ends of the first port recess **128*a***, and both can extend completely through the end plate **102** to enable fluid flow therethrough. The first recess wall **138*a*** can extend partially into the end plate **102** (i.e., recessed into the front surface **123** to a location between the front surface **123** and the back surface **125**) to enable fluid communication between the first workport **134*a*** and the first regen port **136*a***. The second port recess **130*a*** can include a second workport **140*a***, a second regen port **142*a***, and a second recess wall **144*a*** arranged between the second workport **140*a*** and the second regen port **142*a***. The second workport **140*a*** and the second regen port **142*a*** can be arranged at opposing ends of the second port recess **130*a***, and both can extend completely through the end plate **102** to enable fluid flow therethrough. The second recess wall **144*a*** can extend partially into the end plate **102** (i.e., recessed into the front surface **123** to a location between the front surface **123** and the back surface **125**) to enable fluid communication between the second workport **140*a*** and the second regen port **142*a***. The back surface **125** of the end plate **102** can include a supply passageway **146*a***, which defines a recess that extends partially into the end plate **102** (i.e., recessed into the back surface **125** to a location between the front surface **123** and the back surface **125**).

When assembled, the filter plate **104** can be coupled between the end plate **102** and a front surface **148** of the manifold **106**. The filter plate **104** can define a flat, thin plate that includes a plurality of check valve and filter features. In some non-limiting examples, the filter plate **104** can be fabricated from a metal material (e.g., stainless steel) or can be fabricated from a plastic material (e.g., nylon). As shown in FIG. **7**, the filter plate **104** can include a first supply cutout **150*a***, a second supply cutout **152*a***, a first port cutout **154*a***, and a second port cutout **156*a***. Each of the second supply cutout **152*a***, the first port cutout **154*a***, and the second port cutout **156*a*** can include a filter **158*a***, **160*a***, and **162*a***, respectively, formed therein. The illustrated filters **158*a***, **160*a***, and **162*a***, can be in the form of mesh filters configured to filter contaminants and/or particulates in fluid flowing through the respective one of the second supply cutout **152*a***, the first port cutout **154*a***, and the second port cutout **156*a***.

In some non-limiting examples, the filters **158***a*, **160***a*, and **162***a* may be in the form of a metal plate (e.g., stainless steel) having a plurality of small holes arranged thereon.

The filter plate **104** can include a supply check valve **164***a*, a first regen port check valve **166***a*, and a second regen port check valve **168***a*. Each of the illustrated supply check valve **164***a*, the first regen port check valve **166***a*, and the second regen port check valve **168***a* can be in the form of a reed valve hingidly attached to the filter plate **104**. When the filter plate **104** is assembled between the front surface **148** of the manifold **106** and the end plate **102**, the supply check valve **164***a* can be in engagement with the back surface **125**. This can prevent the supply check valve **164***a* from hinging open in a direction toward the end plate **102**, and only allow the supply check valve **164***a* to hinge open in a direction toward the manifold **106**. In this way, the supply check valve **164***a* can allow fluid to flow only in a direction from the supply port **129***a* into the manifold **106**. Similarly, the first regen port check valve **166***a* and the second regen port check valve **168***a* can engage the back surface **125** of the end plate **102**, when assembled. Accordingly, the first regen port check valve **166***a* can allow fluid to flow only in a direction from the first regen port **136***a* into the manifold **106**, and the second regen port check valve **168***a* can allow fluid to flow only in a direction from the second regen port **142***a* into the manifold **106**.

Turing to FIGS. **8** and **9**, the manifold **106** can include a supply chamber **170***a*, a first port chamber **172***a*, a second port chamber **174***a*, a regen chamber **176***a*, and a pre-supply chamber **178***a*. The supply chamber **170***a* can define a recessed chamber in the manifold **106** extending from the front surface **148** to a position between the front surface **148** and a back surface **180** of the manifold **106**. The first port chamber **172***a*, the second port chamber **174***a*, and the regen chamber **176***a* each can define a recessed chamber in the manifold **106** extending from the front surface **148** to a position between the front surface **148** and the back surface **180** of the manifold **106**. The pre-supply chamber **178***a* can include a supply portion **182***a*, a first port portion **184***a*, and a second port portion **186***a*. The supply portion **182***a* can be configured to receive fluid flowing from the supply port **129***a* through the supply check valve **164***a*. The first port portion **184***a* can be configured to receive fluid flowing from the first regen port **136***a* through the first regen port check valve **166***a*. The second port portion **186***a* can be configured to receive fluid flowing from the second regen port **142***a* through the second regen port check valve **168***a*. Thus, fluid flowing through the supply check valve **164***a*, the first regen port check valve **166***a*, and the second regen port check valve **168***a* can flow into the pre-supply chamber **178***a*. As will be described, the pre-supply chamber **178***a* can be in fluid communication with the supply chamber **170***a* via the supply passageway **146***a* in the end plate **102**.

The manifold **106** can include a control valve mounting bore **188***a*, a regen valve mounting bore **190***a*, and a bracket mounting aperture **192***a*. The control valve mounting bore **188***a* can extend into the manifold **106** from a top side **194** to a location between the top side **194** and a bottom side **196**. The control valve mounting bore **188***a* can extend through each of the first port chamber **172***a* and the second port chamber **174***a*. The control valve mounting bore **188***a* can also extend partially through the regen chamber **176***a* and into the supply chamber **170***a*. The regen valve mounting bore **190***a* can extend at least partially through the regen chamber **176***a* and into the supply chamber **170***a*. The regen valve mounting bore **190***a* can include an outlet port **198***a*. The illustrated outlet port **198***a* can define a generally U-shaped cutout in the regen valve mounting bore **190***a* adjacent to the top side **194** of the manifold. The generally U-shaped cutout defined by the outlet port **198***a* can enable fluid to flow through the outlet port **198***a* when the mounting bracket plate **112** is fastened on top of the regen valve mounting bore **190***a*, when the cam phasing control system is assembled. It should be appreciated that the shape (i.e., the generally U-shaped cutout) defined by the outlet port **198***a* is not meant to be limiting in any way and, in other non-limiting examples, the outlet port **198***a* may be designed to define any shape or profile, as desired.

Turning to FIG. **10**, the first control valve **114** can include a housing **200***a* and a spool **202***a*. The housing **200***a* can be coupled to a pole piece **204***a*, which can be partially received within the housing **200***a*. A solenoid **206***a* can be arranged within the housing **200***a*, and can include a wire coil **208***a* wrapped around a bobbin **210***a*. One or more terminals (not shown) may be configured to provide electrical communication between the wire coil **208***a* and a connector **212**. An armature tube **214***a* can be arranged within the housing **200***a*. The armature tube **214***a* can be concentrically arranged inside of the wire coil **208***a*, and an armature **216***a* can be slidably received within the armature tube **214***a*. The illustrated armature **216***a* can be slidably received within the armature tube **214***a* via a plurality of ball bearings **218***a* each received within a corresponding bearing retaining slot **220***a* formed on the armature **216***a*. The armature **216***a* can be coupled to the spool **202***a* by a pin **222***a*. In operation, the wire coil **208***a* can be selectively energized and produce a magnetic force, which, in turn, actuates the armature **216***a* and thereby the spool **202***a* in a desired direction.

The spool **202***a* can be dimensioned to be received within the control valve mounting bore **188***a*. The spool **202***a* can define a generally annular shape with an internal bore **224***a* extending longitudinally therethrough such that fluid can flow into and through the internal bore **224***a* of the spool **202***a*. The spool **202***a* can include a first spool cutout **226***a*, a spool notch **228***a*, and a second spool cutout **230***a*. The first spool cutout **226***a* and the second spool cutout **230***a* can define annular radial recesses in the spool **202***a*. The first spool cutout **226***a* can be longitudinally, or axially, separated from the second spool cutout **230***a* with the spool notch **228***a* arranged therebetween. In operation, as will be described, the first spool cutout **226***a* can enable fluid to flow from the internal bore **224***a* into the second port chamber **174***a*, and the second spool cutout **230***a* can enable fluid to flow from the internal bore **224***a* into the first port chamber **172***a*. The spool notch **228***a* can define a radial recess on an outer surface **231***a* of the spool **202***a*. The spool **202***a* can be biased upwards in a direction toward the housing **200***a* by a spool spring **232***a*. The spool spring **232***a* can be arranged between a distal end **234***a* of the internal bore **224***a* and a spring retainer **236***a*.

Turning to FIG. **11**, the illustrated first regen valve **118** can be in the form of a first poppet **237***a*. The first poppet **237***a* can be dimensioned to be slidably received within the regen valve mounting bore **190***a*. The first poppet **237***a* can include a first end **238***a*, a second end **240***a*, and a tapered portion **242***a* arranged therebetween. The first end **238***a* can include a spring recess **244***a*, which defines an axial recess therein. A biasing element **246***a* can be received within the spring recess **244***a* and can be configured to bias the first poppet **237***a* downward in a direction toward the second end **240***a*. The tapered portion **242***a* includes a tapered surface **248***a* that tapers radially inward as it extends toward the second end **240***a*. The tapered surface **248***a* tapers to a neck portion **250***a* arranged between the first end **238***a* and the second end **240***a*. The neck portion **250***a* defines a reduced diameter compared to the rest of the first poppet **237***a*. It should be appreciated that alternative designs of the first regen valve **118** are possible to achieve similar functionality (i.e., selectively opening in response to a pressure in the supply chamber **170***a*). For example, as shown in FIGS. **12** and **13**, the first regen valve **118** may be in the form of a ball **251***a* biased closed by the biasing element **246***a*, or the first regen valve **118** may be in the form of a swing **253***a*. The various forms of the first regen valve **118** illustrated in FIGS. **11**, **12** and **13** are but three non-limiting examples, and one of skill in the art would appreciate that further alternative configurations may be possible to achieve the desired functionality.

Assembly of the first side **122** of the cam phasing control system **100** will be described with reference to FIGS. **1-14**. It should be appreciated that the assembly of the second side **124** can be similar to the process described below. It should also be appreciated that the order of the process described below is not meant to be limiting in any way and, certainly, other orders of operation are possible and included within the scope of the present disclosure.

Initially, the first control valve **114** can be assembled with the mounting bracket plate **112**. The housing **200***a* of the first control valve **114** can be provided with the internal components (e.g., the solenoid **206***a*, armature tube **214***a*, armature **216***a*, pin **222***a*, etc.) arranged within the housing **200***a*. The pole piece **204***a* can be installed through a control valve aperture **252***a* of the mounting bracket plate **112**. The housing **200***a*, with the internal components arranged therein, can then be coupled over the mounting bracket plate **112** and onto the pole piece **204***a*. The first regen valve **118**, for example, in the form of the first poppet **237***a* of FIG. **11**, can then be installed into the regen valve mounting bore **190***a* and held in place by the tapered surface **248***a* engaging a poppet seat **254***a* within the regen valve mounting bore **190***a*. With the first regen valve **118** installed within the regen valve mounting bore **190***a*, the first regen valve **118** can be in fluid communication with the supply chamber **170***a*. If the required, the biasing element **246***a* can then be installed into the regen valve mounting bore **190***a* on top of the first regen valve **118** such that the biasing element **246***a* can be received within the spring recess **244***a*.

The first control valve **114** with the mounting bracket plate **112** coupled thereto can be installed onto the manifold **106** such that the spool **202***a* is received within the control valve mounting bore **188***a* and a regen valve portion **256***a* of the mounting bracket plate **112** covers the regen valve mounting bore **190***a*. A fastening element (not shown) can be threaded through a bracket aperture **258***a* of the mounting bracket plate **112** and into the mounting aperture **192***a* in the manifold **106**. Upon the fastening element (not shown) being threaded into the mounting aperture **192***a*, the first control valve **114** can be secured to the manifold **106** and the regen valve portion **256***a* of the mounting bracket plate **112** can compress the biasing element **246***a* thereby biasing the first regen valve **118** into a first regen valve position. In the first regen valve position, fluid communication can be inhibited between the regen chamber **176***a* and the outlet port **198***a*. As described above, the outlet port **198***a* can define a generally U-shaped profile, or another profile as desired. This can enable fluid to flow through the outlet port **198***a* with the regen valve portion **256***a* of the mounting bracket plate **112** secured onto the regen valve mounting bore **190***a*.

With the first control valve **114** and the first regen valve **118** secured within and coupled to the manifold **106**, the end plate **102** can be fastened to the front surface **148** of the manifold with the filter plate **104** arranged therebetween to complete the assembly of the cam phasing control system **100**. The assembled cam phasing control system **100** can be coupled, for example, to a cylinder head of an internal combustion engine (not shown) such that the first side **122** of the cam phasing control system **100** is in fluid communication with a first cam phase actuator and the second side **124** of the cam phasing control system **100** is in fluid communication with a second cam phase actuator. Thus, the cam phasing control system **100** described herein provides a bolt-on solution that enables the control of the cam phasing for two cam shafts on an internal combustion engine. The cam phasing control system **100** also significantly reduces the amount of components required to implement the control of two cam phase actuators. For example, the manifold **106** can replace the valve bodies that are included with current cam phase control valves, and a single connector **212** can be used to control both the first and second control valves **114** and **116**. Additionally, the filter plate **104** can provide the functionality of what would require six separate filters and six separate check valves in a current cam phasing control system with a single component.

Operation of the cam phasing control system **100** will be described with reference to FIGS. **1-18** in the context of the first side **122** controlling a flow of fluid to and from a cam phase actuator **260**. It should be appreciated that the second side **124** can be coupled to a second cam phase actuator and the operational capabilities of the second side **124** can be similar to the first side **122**, described below.

In operation, the supply port **129***a* can be in fluid communication with a pump **262** of an internal combustion engine (not shown). The pump **262** can draw fluid (e.g., oil) from a reservoir **264** (e.g., a main oil gallery or oil pan of the internal combustion engine) and furnish the fluid under increased pressure to the supply port **129***a*. The first workport **134***a* can be in fluid communication with a first actuator port **266** of the cam phase actuator **260**. The second workport **140***a* can be in fluid communication with a second actuator port **268** of the cam phase actuator. The outlet port **198***a* can be in fluid communication with the reservoir **264**.

The illustrated spool **202***a* can be a 4-way, 3-position spool moveable between a first spool position **270**, a second spool position **272**, and a third spool position **274**. In the first spool position **270**, the cam phase actuator **260** can rotate the cam shaft in a first rotational direction relative to the crank shaft, which can either advance or retard the intake and exhaust valve events relative to the crank shaft. In the third spool position **274**, the cam phase actuator **260** can rotate the cam shaft relative to the crank shaft in a second rotational direction opposite to the first rotational direction, which can perform the other of advancing or retarding the intake and exhaust valve events when compared to the first spool position **270**. In the second spool position **272**, the cam phase actuator **260** can maintain the rotational relationship between the cam shaft and the crank shaft.

The first regen valve **118** can control an operating mode of the cam phase actuator **260**. That is, that first regen valve **118** can be moveable between a first regen valve position (FIG. **17**) and a second regen valve position (FIG. **18**). When the first regen valve **118** is in the first regen valve position (FIG. **17**), the cam phase actuator **260** can be operable in a regenerative mode. When the first regen valve **118** is in the second regen valve position (FIG. **18**), the cam phase actuator **260** can be operable in an oil pressure actuated mode.

FIGS. **17** and **18** illustrate the spool **202***a* in the first spool position **270**. Upon instruction from, for example, an engine controller unit (ECU) to vary the rotational relationship between the cam and the crank shafts (i.e., vary the intake and exhaust valve timing events), the solenoid **206***a* can actuate the spool **202***a* into the first spool position **270**. When the spool **202***a* is actuated to the first spool position **270**, the first spool cutout **226***a* can provide fluid communication between the supply chamber **170***a* and the second port chamber **174***a* through the internal bore **224***a* of the spool **202***a*. Additionally, the spool notch **228***a* can provide fluid communication between the first port chamber **172***a* and the regen chamber **176***a*.

The pump **262** can supply fluid to the supply port **129***a* and the fluid supplied by the pump **262** can flow through the supply check valve **164***a* and into the pre-supply chamber **178***a*. Fluid communication can be provided from the pre-supply chamber **178***a* into the supply chamber **170***a* via the supply passageway **146***a* in the end plate **102**. Fluid flowing from the supply passageway **146***a* into the supply chamber **170***a* can flow through the filter **158***a* in the second supply cutout **152***a* thereby filtering contaminants and/or particulates prior to entry into the supply chamber **170***a*.

The fluid in the supply chamber **170***a*, which is supplied by the pump **262**, can apply a force to the first regen valve **118** in a direction towards the outlet port **198***a*. Simultaneously, the fluid in the supply chamber **170***a* can flow through the internal bore **224***a* of the spool **202***a* and into the second port chamber **174***a*. From the second port chamber **174***a*, the fluid can flow to the second workport **140***a* through the filter **162***a* and to the second actuator port **268** of the cam phase actuator **260**. Thus, in the first spool position **270**, pressurized fluid can flow from the pump **262** to the second actuator port **268**. With pressurized fluid entering the second actuator port **268**, fluid can flow from the first actuator port **266** towards the first workport **134***a*. Where the fluid flows once it reaches the first workport **134***a* depends on the fluid pressure in the supply chamber **170***a* supplied by the pump **262**. That is, if the pump pressure supplied to the supply chamber **170***a* is below a regen pressure threshold (i.e., the pump pressure applies a force to the first regen valve **118** that is unable to overcome the opposing force applied by the biasing element **246***a*), the first regen valve **118** can remain in the first regen valve position (FIG. **17**).

With the first regen valve **118** in the first regen valve position (FIG. **17**), the fluid flowing from the first actuator port **266** to the first workport **134***a* can be inhibited from flowing through the regen chamber **176***a* to the outlet port **198***a*. The fluid can then be forced to flow into the first regen port **136***a* through the first regen port check valve **166***a* and into the pre-supply chamber **178***a*. Once in the pre-supply chamber **178***a*, the fluid can flow into the second actuator port **268**, as described above. Thus, in the first regen valve position, the first regen valve **118** can enable the fluid flowing from the first actuator port **266** to regenerate and flow back into the second actuator port **268**. This can enable the pump **262** to only provide make-up flow due to leakage losses. Additionally, the cam phase actuator **260** can operate in a regenerative mode where the cam phase actuator **260** can harvest cam torque pulses applied thereto by the cam shaft to alter the rotational relationship between the cam shaft and the crank shaft.

If the pump pressure supplied to the supply chamber **170***a* is above a regen pressure threshold (i.e., the pump pressure applies a force on the first regen valve **118** in a direction towards the outlet port **198***a* that is sufficient to overcome the opposing force applied by the biasing element **246***a*), the first regen valve **118** can move to in the second regen position (FIG. **18**). In the second regen valve position, the first regen valve **118** can be displaced and provide fluid communication between the regen chamber **176***a* and the outlet port **198***a*.

With the first regen valve **118** in the second regen valve position (FIG. **18**), the fluid flowing from the first actuator port **266** can flow into the first workport **134***a*, through the filter **160***a*, and into the first port chamber **172***a*. The fluid in the first port chamber **172***a* can then flow past the spool notch **228***a* and into the regen chamber **176***a*. Once in the regen chamber **176***a*, the fluid can flow through the outlet port **198***a* to the reservoir **264**. Thus, in the second regen valve position, the cam phase actuator **260** can operate in an oil pressure actuated mode where the pressurized fluid supplied by the pump **262** to the second actuator port **268** can alter the rotational relationship between the cam shaft and the crank shaft. It should be appreciated that the regen pressure threshold can be tunable. That is, a biasing element **246***a* with a desired stiffness (i.e., provides a desired force on the first regen valve **118** in a direction away from the outlet port **198***a*) can be selected to determine the pump pressure that actuates the cam phase actuator **260** between the regenerative mode and the oil pressure actuated mode.

The operation of the first regen valve **118** can be similar when the spool **202***a* is actuated into the second spool position **272** and the third spool position **274**. In the second spool position **272**, the spool **202***a* can provide fluid communication between the pump **262** and both the first actuator port **266** and the second actuator port **268** to maintain a rotational relationship between the cam shaft and the crank shaft. The operation of the third spool position **274** can be opposite to the first spool position **270**, described above, with the pump supplying fluid to the first actuator port **266**, and the fluid from the second actuator port **268** either regenerating back to the first actuator port **266** or flowing to the reservoir **264**.

It should be appreciated that alternative designs, arrangements, and configurations of the cam phasing control system **100** may be possible to achieve the operational aspects of the system, described above. That is, in some non-limiting examples, the cam phasing control system **100** may not include the end plate **102** and/or the filter plate **104**. Instead, the functionality of the check valves and filters on the filter plate **104** may be integrated into the manifold **106** and/or accomplished external from the manifold **106** on a given application.

FIGS. **19** and **20** illustrate the first side **122** an alternative configuration of the cam phasing control system **100** according to another non-limiting example of the present disclosure. As shown in FIGS. **19** and **20**, the cam phasing control system **100** may not include the end plate **102** and the filter plate **104**, and can include the first regen port check valve **166***a* and second regen port check valve **168***a* integrated into the manifold **106**. The supply check valve **164***a* (not shown) may be arranged on a supply line (not shown) in fluid communication with the supply chamber **170***a*. Additionally, the filters **158***a*, **160***a*, and **162***a* (not shown) may be arranged externally from the manifold **106**. The cam phasing control system **100** of FIGS. **19** and **20** can achieve similar operation and performance as the cam phasing control system **100** of FIGS. **1-18**.

The cam phasing control system **100** described herein can provide a bolt-on solution that enables the control of the cam phasing for two cam shafts on an internal combustion engine. The cam phasing control system **100** can also significantly reduces the amount of components required to implement the control of two cam phase actuators.

Thus, while the invention has been described above in connection with particular embodiments and examples, the invention is not necessarily so limited, and that numerous other embodiments, examples, uses, modifications and departures from the embodiments, examples and uses are intended to be encompassed by the claims attached hereto. The entire disclosure of each patent and publication cited herein is incorporated by reference, as if each such patent or publication were individually incorporated by reference herein.

We claim:

**1**. A cam phasing control system configured to be coupled to an internal combustion engine for controlling a flow of fluid to and from a cam phase actuator, the internal combustion engine including a pump, a cam shaft, and a crank shaft, the cam phase actuator including a first actuator port and a second actuator port, the cam phasing control system comprising:

a manifold including a supply chamber, a first port chamber, a second port chamber, a regen chamber, and an outlet port;

at least one control valve including a solenoid and a spool moveable between a plurality of positions in response to activation of the solenoid, wherein the spool is slidably received within the manifold; and

at least one regen valve arranged within the manifold and in fluid communication with the regen chamber, wherein the at least one regen valve is moveable between a first regen valve position where fluid communication is inhibited from the regen chamber through the outlet port and a second regen valve position where fluid communication is provided from the regen chamber through the outlet port, wherein the at least one regen valve is moveable between the first position and the second position in response to a pressure in the supply chamber,

wherein when the at least one regen valve is in the first regen valve position, the cam phase actuator is operable in a regenerative mode, and when the at least one regen valve is in the second poppet position, the cam phase actuator is operable in an oil pressure actuated mode.

**2**. The cam phasing control system of claim **1**, wherein each of the supply chamber, the first port chamber, and the second port chamber are formed within the manifold.

**3**. The cam phasing control system of claim **1**, wherein when the at least one regen valve is in the first regen valve position, fluid communication is provided between one of the first port chamber and the second port chamber and the supply chamber.

**4**. The cam phasing control system of claim **1**, wherein when the at least one regen valve is in the second regen valve position, fluid communication is provided between one of the first port chamber and the second port chamber and the outlet port.

**5**. The cam phasing control system of claim **1**, further comprising a supply check valve to enable fluid to flow only in a direction from the pump to the supply chamber.

**6**. The cam phasing control system of claim **1**, further comprising a first regen check valve to enable fluid to flow only in a direction from the first port chamber to the supply chamber.

**7**. The cam phasing control system of claim **6**, wherein the first regen check valve is integrated into the manifold.

**8**. The cam phasing control system of claim **1**, further comprising a second regen check valve to enable fluid to flow only in a direction from the second port chamber to the supply chamber.

**9**. The cam phasing control system of claim **8**, wherein the second regen check valve is integrated into the manifold.

**10**. The cam phasing control system of claim **1**, further comprising an end plate including a supply port, a first workport, a first regen port, a second workport, and a second regen port, wherein the first workport is in fluid communication with the first actuator port and the first port chamber, the second workport is in fluid communication with the second actuator port and the second port chamber, and the supply port is in fluid communication with the pump and the supply chamber.

**11**. The cam phasing control system of claim **10**, wherein the manifold includes a pre-supply chamber in fluid communication with the supply chamber via a supply passageway formed in the end plate.

**12**. The cam phasing control system of claim **10**, wherein the first workport is in fluid communication with the first regen port and the second workport is in fluid communication with the second regen port.

**13**. The cam phasing control system of claim **1**, further comprising a filter plate including a plurality of check valves and a plurality of filters formed thereon.

**14**. The cam phasing control system of claim **13**, wherein the filter plate includes a first regen port check valve, a second regen port check valve, and a supply check valve.

**15**. The cam phasing control system of claim **14**, wherein the first regen port check valve enables fluid to flow only in a direction from the first port chamber to the supply chamber.

**16**. The cam phasing control system of claim **14**, wherein the second regen port check valve enables fluid to flow only in a direction from the second port chamber to the supply chamber.

**17**. The cam phasing control system of claim **14**, wherein the supply check valve enables fluid to flow only in a direction from the pump to the supply chamber.

**18**. The cam phasing system of claim **14**, wherein each of the first regen port check valve, the second regen port check valve, and the supply check valve are reed valves.

**19**. The cam phasing control system of claim **13**, wherein the filter plate includes a first filter, a second filter, and a third filter.

**20**. The cam phasing control system of claim **19**, wherein the first filter is arranged to filter fluid flowing into the supply chamber.

**21**. The cam phasing control system of claim **19**, wherein the second filter is arranged to filter fluid flowing into and out of the first port chamber.

**22**. The cam phasing control system of claim **19**, wherein the third filter is arranged to filter fluid flowing into and out of the second port chamber.

**23**. The cam phasing control system of claim **1**, wherein the manifold is symmetric about a center plane.

**24**. The cam phasing control system of claim **23**, wherein the manifold includes another supply chamber, another first port chamber, another second port chamber, another regen chamber, and another outlet port.

**25**. The cam phasing control system of claim **24**, wherein the at least one regen valve comprises a first regen valve and a second regen valve and the at least one control valve comprises a first control valve and a second control valve.

**26**. The cam phasing control system of claim **25**, wherein the first control valve and the second control valve are coupled to the manifold by a mounting bracket plate.

* * * * *